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OBSERVATIONS

ON THE

RICH PARTS OF THE LODES

OF CORNWALL,

Their Form, and their Relations with the Directions of the Stratigraphic Systems.

BY

PROFESSOR L. MOISSENET,

OF THE "ECOLE DES MINES," PARIS, HONORARY MEMBER OF THE MINERS' ASSOCIATION
OF CORNWALL AND DEVON, THE ROYAL GEOLOGICAL SOCIETY OF CORNWALL,
Etc., Etc.

TRANSLATED FROM THE FRENCH BY

J. H. COLLINS, F.G.S.,

HON. SECRETARY TO THE MINERS' ASSOCIATION OF CORNWALL AND DEVON, THE ROYAL
INSTITUTION OF CORNWALL, AND THE MINERALOGICAL SOCIETY OF GREAT BRITAIN
AND IRELAND; AUTHOR OF A HANDBOOK TO THE MINERALOGY OF CORNWALL AND
DEVON, Etc., Etc.

DEC 1877
BODLEIANA

LONDON:
SIMPKIN, MARSHALL, AND Co., STATIONERS' HALL COURT.
TRURO:
LAKE AND LAKE, PRINCES STREET.
1877.

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TRANSLATOR'S PREFACE.

The Report of the Council of the Miners' Association of Cornwall and Devon, in June 1874, in recommending Professor Moissenet for election as an Honorary Life Member, contained the following reference to his works.

"M. Moissenet, the distinguished French Mining Engineer, has lately written some valuable works on Lode-Mining, and of one of these, which treats especially on the veins of Cornwall, it is proposed to publish an abstract for the use of the members of the Association. This abstract will be made by your Honorary Secretary (Mr. J. H. Collins), and it will be submitted to M. Moissenet before publication."

In accordance with this announcement, I commenced the abstract in question, but I soon found that the work was already so well condensed that very little abridgement was possible, if any considerable proportion of its usefulness was to be preserved. Under these circumstances, and after renewed communications with the author, I determined to make a complete translation, and as the work in its complete form was too large to be issued in the proceedings of the Miners' Association, I was compelled to undertake the whole responsibility—pecuniary and otherwise.

A considerable proportion of the cost is, however, secured by the subscription list which appears at the end of the volume, and I trust the book in its present form may prove so useful to students that the whole edition—which is limited to 400 copies—will be soon off my hands.

In preparing this translation I have, as was to be expected, sometimes met with words having in their applications to mining, no exact English equivalents, as for instance, *exploitation*, *gîte*, *cannelure*, *allure*, *roideur*, and *plongement*. The last two have generally been translated *underlie* and *dip* respectively, but the former term is manifestly inapplicable as applied to the typical case (unusual I admit) of a vertical fissure; and the latter is a word used in a quite different sense by all geologists, and a majority of miners. I believe our mining language would gain much in precision if all these words could be naturalized.

It is possible that some readers may discover that I have followed the French idiom somewhat too closely in a few instances; I am quite aware that this is the case but I will urge in my own defence that it is more conducive to an exact appreciation of the author's meaning than a too free translation.

In one respect the book is more valuable than the original French edition, as it contains an appendix A (with plate,) which was not in that edition. This appendix explains briefly the numerous references to the *Systems* and the *Theories* of M.Elie de Beaumont—a subject but little known hitherto to English Mining Students. The convenience of getting text and plates all into one volume will, I believe, fully compensate for the reduced scale of the plates—which in the original edition were formed into a quarto atlas.

J. H. COLLINS,

Truro, June 19, 1877.

AUTHOR'S PREFACE.

Twenty-two years ago, I visited England for the first time; I was then a student provided with the varied and general instruction to be acquired at the "*Ecole des Mines*," and was anxious to get some, and any, practical knowledge.

The magnitude of the underground and surface workings of the Cornish mines impressed me deeply, and having had a glimpse of the enormous number of "mining facts" concentrated in the county of Cornwall, and of the large supply of information already treasured in the local scientific records, I resolved to come over again to such a grand practical school. Thus I was led to take a peculiar interest in the study of metalliferous deposits, and was struck with the desire to become a devôted, and if possible, a useful member of the mining community.

Circumstances favored my object; at home, my eminent masters, Mr. L. Elie de Beaumont, and my chief in the Laboratory of the School, Mr L. E. Rivot, gave me a constant support, so that I could then almost every summer interweave my official duties with the practice of mining in France and with studies abroad, and especially in Cornwall.

On the other hand, I had from the commencement met in England with an invaluable patron, Mr. Robert Hunt, who introduced me to the world of the mines. I wish I might better state here all the scientific and moral assistance I derived from him throughout the long course of my enquiries. I wish also to acknowledge my indebtedness to the mine owners, managers, agents, and others who constantly facilitated my studies in Cornwall and Devon, among them I cannot refrain from inserting here the name of my most venerated friend, the late W. Jory Henwood.

My labours, and some troubles almost unavoidably connected with much travelling underground, have already been amply repaid by the welcome given to the French edition of this work, and the honours granted me by the Royal Geological Society of Cornwall, the Royal Cornwall Polytechnic Society, the Royal Institution of Cornwall, and the Miners' Association of Cornwall and Devon.

The present translation originated in a resolution of the Council of the Miners' Association to publish an abstract of my "Etudes, parties riches," in its proceedings, and has reached its present complete and elaborate form through the talented zeal and skilful pen of the Honorary Secretary, Mr J. H. Collins. I have carefully reviewed the proof sheets in the course of printing, but I confess that, from the translator's ability, I have had but little share in the present work.

L. Moissenet.

Paris, June 16th, 1877.

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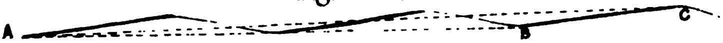

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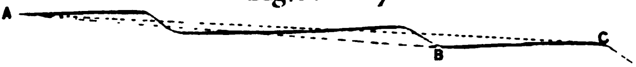

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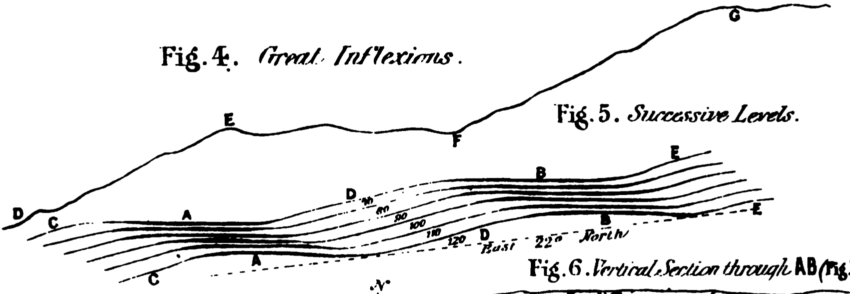

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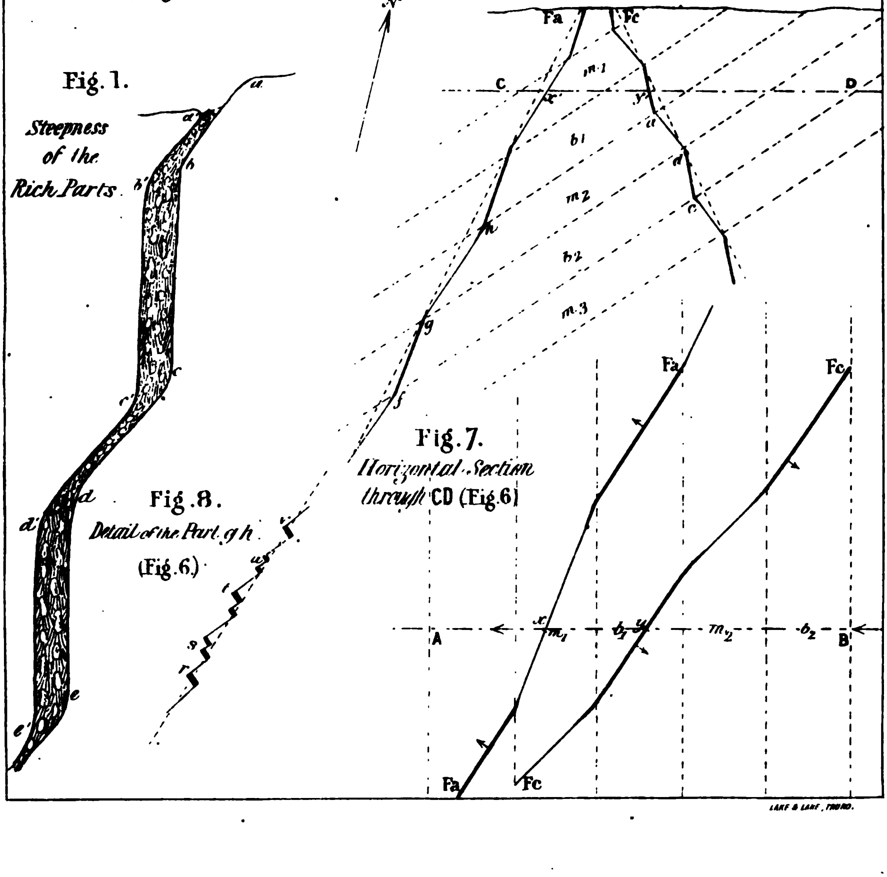

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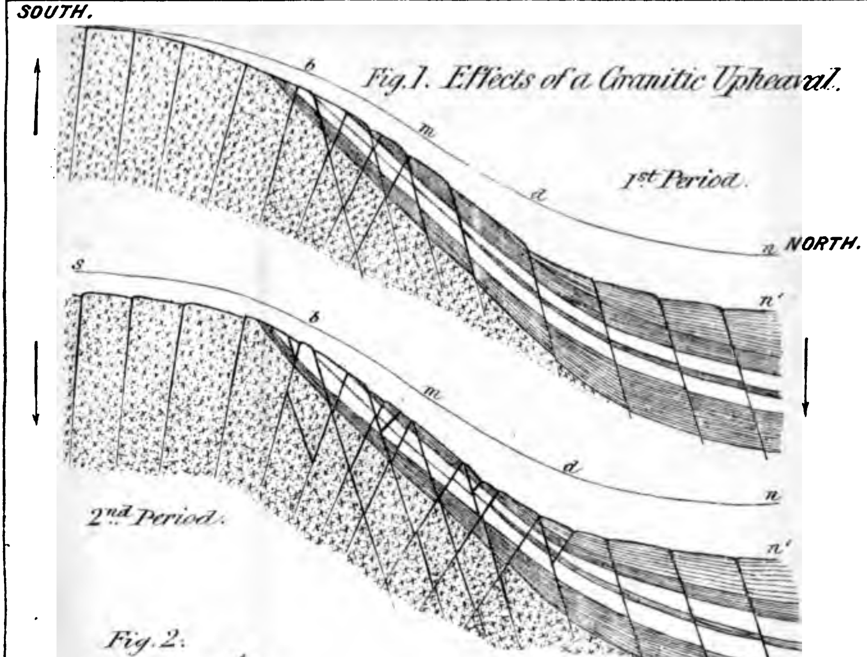
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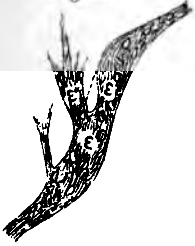
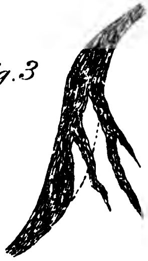
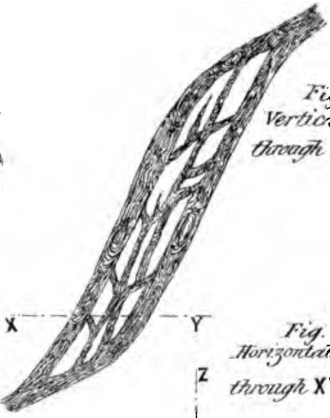


Fig. 3

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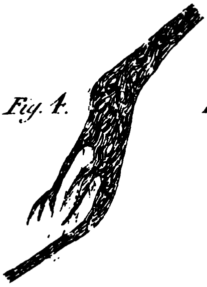
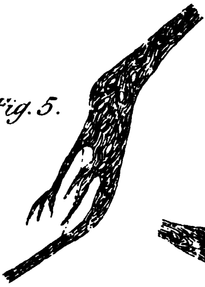


Fig. 5.



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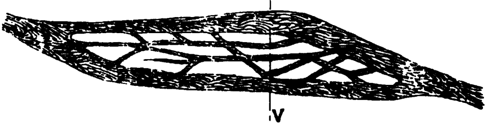

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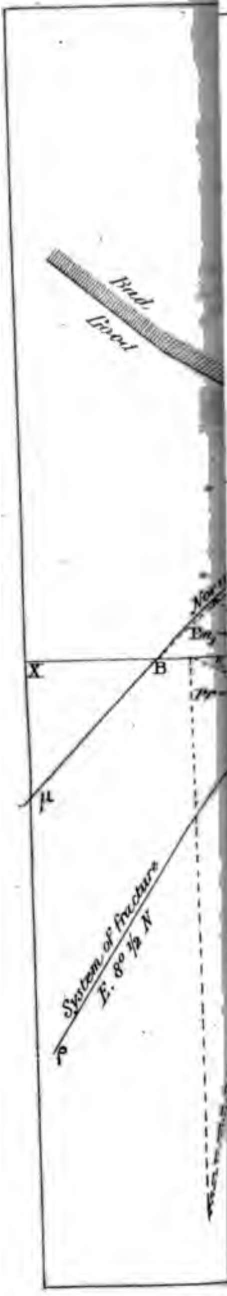

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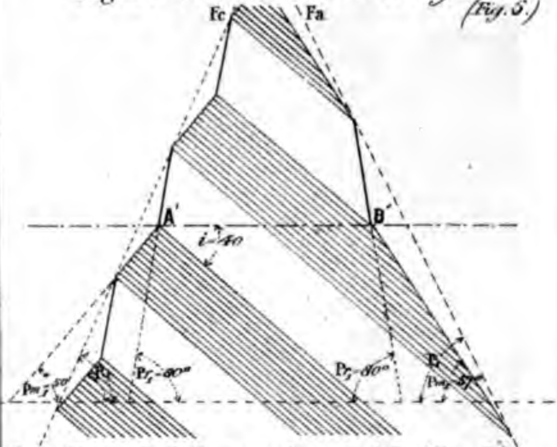

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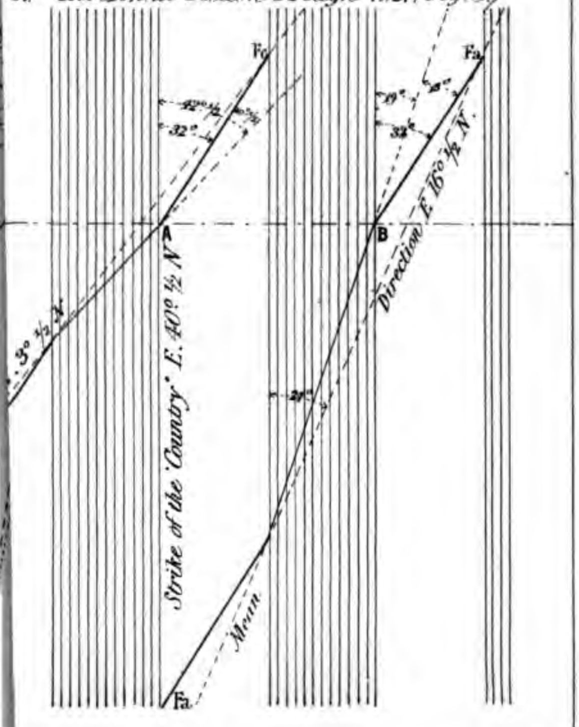

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Plate V.

LODE Fa.

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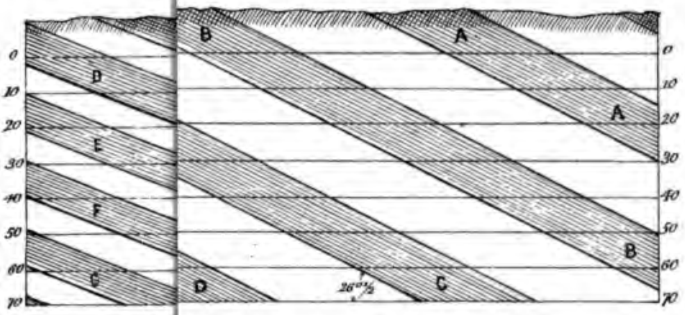

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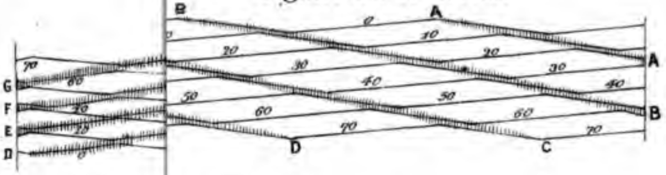

Fig. 5.

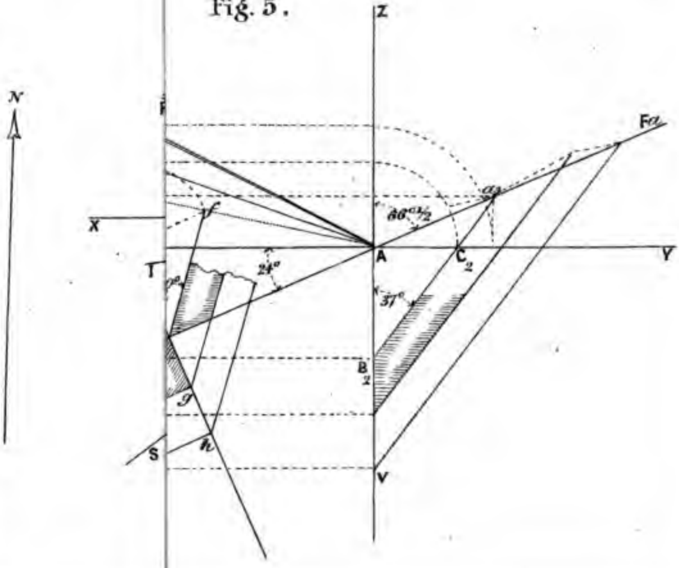

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Plate VI.

LODES & CROSS-COURSES
in the neighbourhood of Carn Brea
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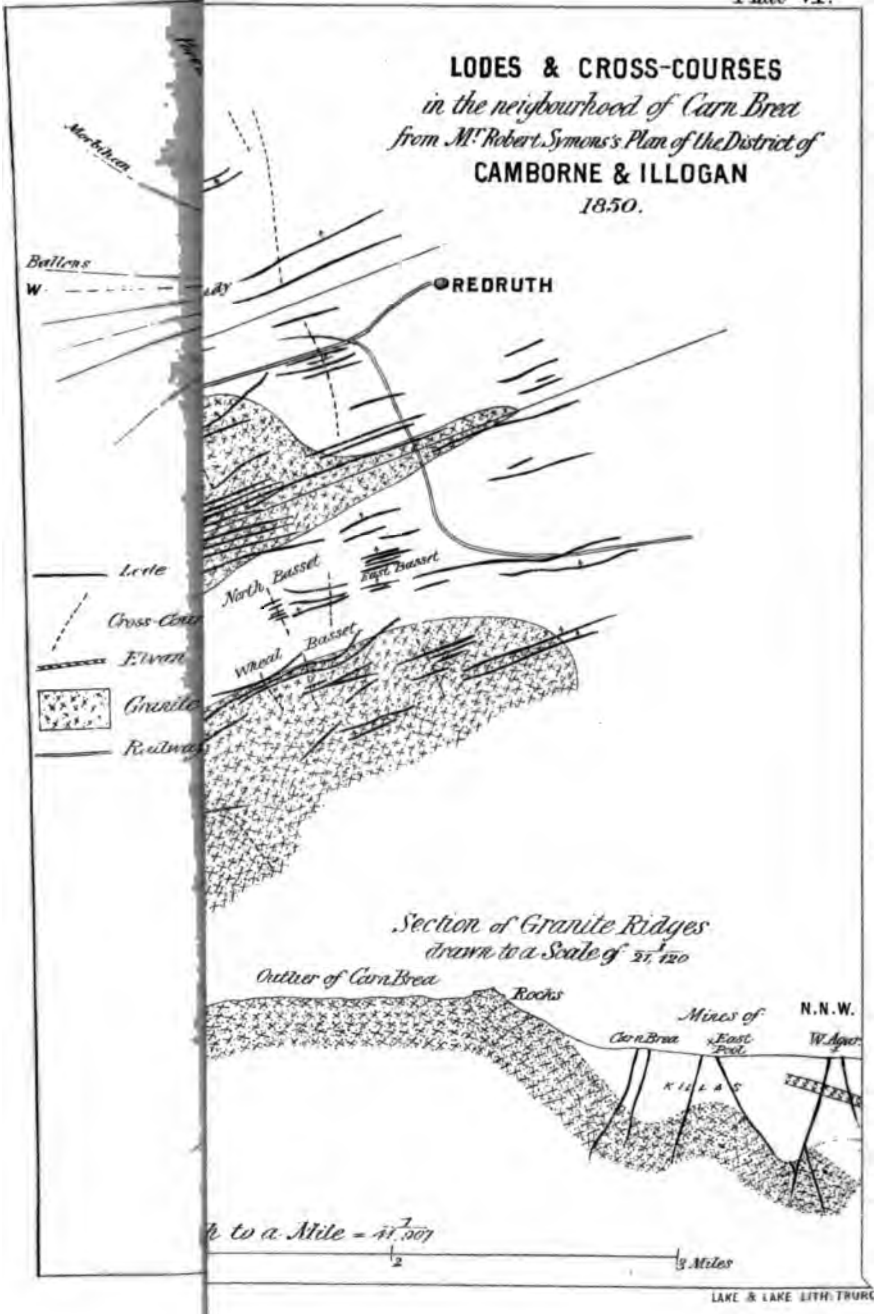
CAMBORNE & ILLOGAN
1850.



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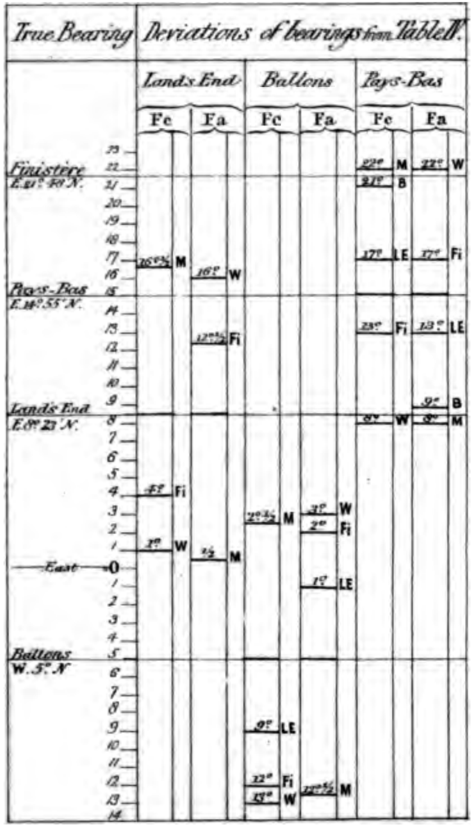

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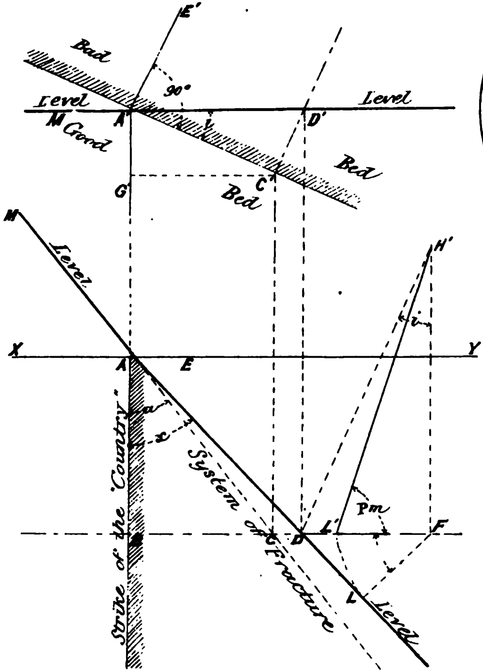
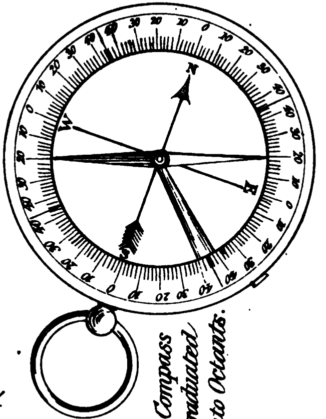


Fig. 4.



Compass graduated into Octants.

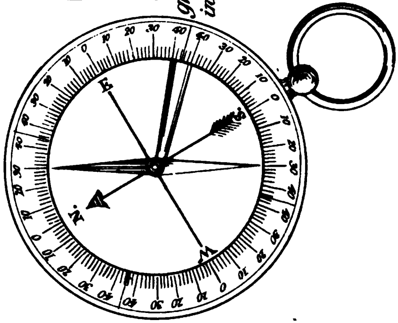


Fig 3.

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Plate VIII.

Sketches illustrating the Mountain Systems & the réseau pentagonal of M. Elie de Beaumont.

Gnomonique Projection of One of the 12 Pentagons on the horizon of its centre.

Scale of $\frac{1}{100,000,000}$

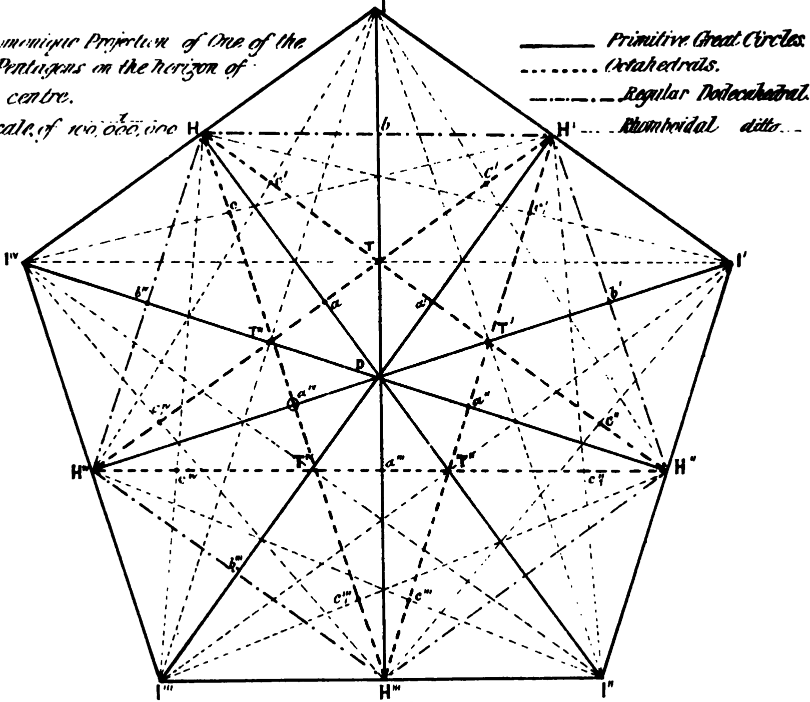

Fig. 10.

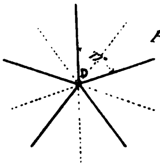

Fig. 5.

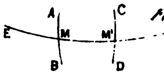

Fig. 1.

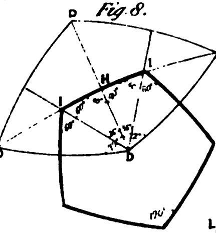

Fig. 8.

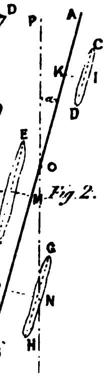

Fig. 2.

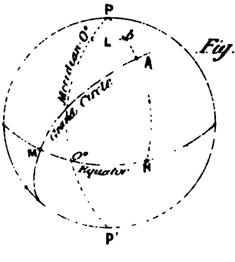

Fig. 3.

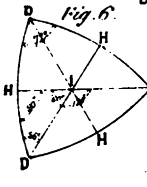

Fig. 6.

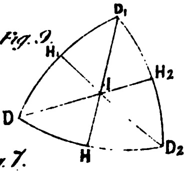

Fig. 9.

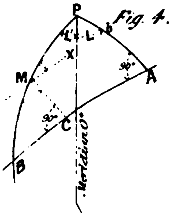

Fig. 4.

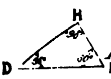

Fig. 7.

LAKE & LAKE, LITH TRURO.

INTRODUCTION.

THE mineral riches of lodes are almost always very unequally distributed, and the workings afford evidence of sterile zones, as well as of others which are productive in different degrees.

In most of the lodes the rich parts constitute, so to speak, a series of "mines within the mine;" and it is naturally upon these parts that the work of "exploitation" is concentrated, whereas the "poor" parts are simply cut through by the necessary galleries of communication.

The form and relative position of these rich parts correspond pretty accurately with the places from whence most of the mineral is broken. As the geometric projection of these excavations presents a kind of outline of the masses removed, if the works have been well conducted, the traces thus obtained differ but little from the natural limits of the rich parts.

If the situation and configuration of these rich parts could be foreseen, the exploitation of metalliferous lodes would lose its haphazard character, and the engineer would be enabled to devote his whole attention, as in other industries, to the economic conditions and technical proceedings most suited to each particular case. The miners—turning tradition to account—proceeding by analogy and comparison, try to overcome chance; and by conjectures based upon experience—making use of the smallest indications by most remarkable foresight—often ascertain the general conditions of the deposit (*gîte*).

For the observant miner the phenomena to be seen in the lodes are so numerous that each one opened by his labours imprints on his memory some particular recollection, while their peculiarities give to each a kind of individuality. The same remark applies to general facts: each mining district has its own character; each group of districts or mining country is distinct from all others from the point of view with which we are concerned, viz., the peculiarities of the rich parts. These variations result mainly from a fact universally recognized, viz., that the general character of the veins, and consequently their riches, depend upon the nature of the containing rocks.

This common fact results from the common mode of origin of the lodes. The rocks have been fractured, so producing subterranean channels for the circulation of mineral waters. The rocks have, therefore, been subjected unequally, and with a varying intensity, during one or more geological periods, to the action of those physical and chemical forces which have determined their mineral contents.

To take some examples from England. The lodes of tin, copper, and lead in Cornwall and Devon traverse primary schists; those of tin and copper also penetrate the granite, elvan ("quartz porphyry"), and greenstones ("hornblendic rocks"). The lead mines of Wales (Cardiganshire, &c.) are in silurian schists, far from eruptive rocks, while the lodes of galena in the North of England occur in carboniferous strata. In each of these countries metalliferous zones or regions may be distinguished where the strata or beds are productive, and the rocks favourable for mineral.*

The disposition of the lead lodes of the Mountain Limestone in steps ("*gradins*") is well-known. This formation includes beds of limestone and of quartzose sandstones, alternating with argillaceous schists, which are but little inclined. The hard limestones and sandstones ("firestone") have been fractured almost vertically, and these contain the mineral riches; whilst in the schist the lodes are reduced to the state of thin veins, or flat and sterile fissures. To these lodes the *pipe veins* and *flats* are attached;

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* Such expressions as *good channel of ground*, *mining zone*, *suitable strata*, *bearing ground*, *kindly*, *&c.*, are used to qualify the terms *killas*, *granite*, or *elvan*.

these are accessory deposits occurring in some of the limestone beds. The mechanical and chemical actions in these lodes are distinctly appreciable although superposed. When the lode passes through silicious rocks the walls are but little corroded, but in the limestones the chemical action of the circulating waters upon the walls is largely associated with the force of gravity, and has been able to contribute greatly to the formation of the cavity. In all mining countries, wherever calcareous strata are met with, we are at once convinced of their great influence upon the general character of the lodes, but in formations consisting entirely of schistose rocks it is only by the most minute observation that we are able to distinguish practically between the good and bad strata. Still, in the silurian schists of Cardiganshire the miner does not fail to distinguish the favourable strata by their physical characters; he prefers compact schists of moderate hardness, but dislikes the very soft argillaceous schists ("mudstones") and the fissile schists passing into slate.

In these veins of galena, as in those of the Mountain Limestone, the mechanical action of gravity has predominated in the formation of the cavities, i.e., the configuration of the rich parts, but here it is more difficult to recognize the effects of chemical action upon the walls.

In Cornwall and Devon some of the lodes are entirely in schist, others entirely in granite, while others again cut through both these rocks, and often the elvans and greenstones also. To this variety of enclosing rock* is added that of the minerals and veinstones. Notwithstanding the absence of calcareous beds, chemical action is evident in the lodes; it is powerfully developed in a great many places, and notably in those stanniferous deposits which abound in tourmaline.† Nevertheless, the fractures and relative displacements of the encasing rocks do not cease to be discernable, and in spite of the complexity of the phenomena we may follow in the lodes of the two counties, very clearly, the directions of the "stratigraphic systems" to which they belong.

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* "*Country.*"

† "*Schorl*" or "*cockle,*" are the Cornish miners terms for black tourmaline.

Without losing sight of the action of chemical forces upon the "country," we shall avail ourselves of the force of gravity, which is not masked, and we shall seek in the physical properties of the rocks the first cause of the configuration of the rich parts.

In selecting Cornwall as a field of study, I would recall the opinion expressed by Mr. R. W. Fox in his excellent memoir "On Mineral Veins."* "I believe it will be found, on investigation, that the mineral veins of Cornwall differ very little from those which have been observed in other mining districts in what may be termed their mechanical characters."†

The works of English geologists treating of Cornwall and Devon are both numerous and varied; they embrace, collectively and in detail, the two sides of the subject, General Geology and Metalliferous Deposits.

It will be sufficient to mention here:—

The Transactions and Annual Reports of the Royal Geological Society of Cornwall.

The fine work of Sir H. De la Beche, "Report on the Geology of Cornwall, Devon, and West Somerset, 1839," and, by the same author, the memoir "On the formation of the rocks of South Wales and South Western England, 1846."

Different memoirs by Sir R. Murchison.

J. Carne, "On the Relative Age of the Veins of Cornwall, 1822."

R. W. Fox, "On Mineral Veins, 1836.'

W. J. Henwood, "Metalliferous Deposits of Cornwall and Devon, 1843."

Two volumes "On Metalliferous Deposits and on Subterranean Temperature," published in 1871, by Mr. Henwood, which refer to mines situated in Cornwall, as well as in different parts of the globe.

I would mention, also, Mr. Charles Thomas's interesting "Remarks on the Geology of Cornwall and Devon, in connexion with the deposits of metallic ores, and on the bearings of productive lodes," published in 1859; also the very able descriptions of mines given by Mr. H. C. Salmon in the Mining Journal, and in 1862-4, in the Mining and Smelting Magazine.

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* Report of the Royal Cornwall Polytechnic Society, 1836, pp. 81—141.

† Ibid., p. 96.

In 1862 I presented, in the succint form of conclusions, the principal results which I believed I could draw from the application of the directions of the *Stratigraphic Systems*‡ to the study of general geology, and of the deposits of Cornwall. I hoped then to have been able to develope the evidence of these statements in a series of memoirs, shewing, in the first place, *the influence of the eleven most ancient systems upon the general mass of Cornwall and Devon;* in a second work to examine each of the more important metalliferous districts; and finally, to complete the practical object of these researches by pointing out how the miner might apply these ideas, which are less abstract than one might suppose, to the working of the veins.

In 1865 I had drawn up a good part of the first memoir, and laid down pretty carefully the lines of direction upon the map of Cornwall, but since then a variety of circumstances have obliged me to suspend my project, and induced me to present at first such partial results of my studies as seem to me more directly useful to the miner.

I shall rely upon the observations which I was able to make in Cornwall at different times between the years 1855 and 1866, and I shall draw abundantly upon the English works already mentioned, and especially those of Mr. W. J. Henwood. This presents an immense collection of personal observations, together with the fruits of a vast erudition. In bringing together these rich materials the author has treated them with the most scrupulous reserve. In his "Address delivered as President of the Royal Institution of Cornwall," in 1871, he summarized his observations on metalliferous deposits, and in spite of his modest denial he has contributed some general rules of inestimable value for the guidance of the miner.*

The present work consists of two chapters; in the first I describe the different forms of the rich parts, and indicate the general characters of those parts, and I conclude by shewing their mutual connection with each other.

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‡ See appendix A.

* The geological portion of this address was published in the "Report of the Miners' Association of Cornwall and Devon for 1872." J. H. C.

In the second chapter, making use of hypothesis, I apply the conclusions of the first chapter to the study of the subterranean channels produced by the fracture and movements of the ground.

In a résumé, taking the lodes of Cornwall for example, my aim is to shew how the knowledge of the directions of the Stratigraphic Systems may be made useful to the miner, and how that knowledge may be acquired by a series of observations properly made underground.

OBSERVATIONS

ON THE

LODES OF CORNWALL.

CHAPTER I.

1.—*Riches and Poverty in the Lodes.*

MOST of the metalliferous veins present, as is well-known, very great variations of riches in their different parts. In one place the lode is *sterile* through the entire absence of useful minerals; in another it is *unproductive*, because the proportion of such minerals is not sufficient to *pay cost*, elsewhere the lode is called *productive* or *rich*, at such places as, all expenses being paid, its exploitation leaves a more or less considerable profit.

It is evident that these terms depend principally upon pecuniary conditions and results, varying much in the same lode with the conditions of labor and the market value of the mineral, but at any given moment, and under specified modes of working, the miner is enabled by his experience to apply these epithets pretty accurately.

One type of riches is a "strong" lode containing mineral of a *massive* or at least a *well-marked* character. These conditions are often accompanied by a vein-stuff of moderate hardness, and a considerable stability in the "walls" of the lode so that the labor of the miner is lessened, and the expenses of "breaking," "tramming," and "dressing," are reduced to a minimum. The elements of poverty on the contrary are, a lode thin and hard, and often subdivided into threads. The "country," also, is hard and troublesome for drivage; or else, on the contrary, both vein and country are too soft, and therefore fall together. The vein may not perhaps be really small, taking into account its numerous branches, but the mineral is so disseminated through the earthy matter of the vein-stone in little spots or threads, that the expenses of "breaking," "timbering," and "stulling" swallow up all the profit.

In the different districts of Cornwall, and even in the lodes of the same district, the *rich parts* do not equally include the favorable elements above-mentioned. Thus, in the St. Just district, most of the lodes, both of tin and copper, are *rich*, not because of their size, but by the *concentration* of their mineral contents. Elsewhere, a "low produce" ore occurs in great quantity, and, thanks to modern progress, such masses may be worked at a profit, and deserve to be styled "rich parts."

Without dwelling upon these special facts it will be admitted that in nearly all the mines of Cornwall, a large vein of good average quality is called *rich*. Regions which are distinctly productive may be called *rich parts*, although in different degrees, while those which are unproductive are *poor parts*.

2.—*Different kinds of Rich Parts.*

In France the rich zones of the lodes are called "metalliferous columns," (*colonnes métallifères*) "beaded-veins" (*filon-en-chapelet*), and "masses" (*amas*). The miners of Cornwall have the terms "Course," "Shoot," and "Bunch," as well as "Branch" "Floor," and "Carbona," these terms having reference to the principal forms of the rich parts.

Course of Ore.—Wherever a "level" is driven in a rich lode for a great distance without meeting with unproductive gaps and the same conditions occur in the neighbouring levels we have a "Course of Ore" as shewn in Fig. 1, Pl. I. The rich part constitutes a great band, zone, or inclined column, varying somewhat in size and riches, but continuing for a great distance horizontally, 150, 200, 400 yards for example, or even more. The approximate axis of this irregular mass generally makes a small angle with the horizontal.

SHOOT OF ORE.—The word shoot applies to a branch, but also to a sloping passage or arch. Somewhat in this latter sense it is applied to a mass whose chief extension is in depth, the main axis making a pretty large angle with the horizontal, as in Fig. 4, Pl. I. The different shoots in the same mine often dip in the same direction as in the figure.* The distinction made by the miners between Courses and Shoots answers to well-known examples in the different districts, but rich parts are often met with whose form is intermediate between these extreme types, there is, in fact, a true passage from one to the other.†

A great "course of ore" assures to the miner a considerable profit and a rapid return for his outlay, whereas the occurrence of many shoots extending to a great depth secures a mine which, if well-managed, will keep up fair returns for a long time.

BUNCH OF ORE.—This is a rich mass in the lode; some districts are essentially *bunchy*, the ore occurring in the vein in a succession of bunches, like a string of beads.

Sometimes one large bunch or principal mass is met with, more often a series of bunches of variable importance which occur on a common axis, coinciding pretty nearly with the plane of the lode. The term bunch applies especially to the *number* in opposition to the *size* of the masses in the lode. A very small bunch is called a *squat*.

The working of such deposits necessitates much preparatory labor or "dead-work;" and it is only by constantly exploring in advance of the actual workings that a regular production can be maintained.‡

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* This figure represents part of the lead lode at Snailbeach in Shropshire. It is a fine type of shoots, a kind of natural diagram for comparison with the less marked shoots of Cornwall.

† Mr. Henwood, in his "Address" provides against ambiguity by giving a distinct signification to each of the terms. He defines *courses* as metallic masses, and confines the term *shoot* to the "dip" or "underlie." I will add that the term *course* involves the idea of riches and magnitude, and deserves such epithets as *rich*, *good*, *great*; the shoot which is eminently variable in quality and importance, is especially an *inclined* column; in an east and west lode we should say the shoots dip *east* or dip *west*.—Rep. Min. Assoc. Cornwall and Devon, 1872, p. 11.

‡ Fig. 1 shews to the east of a great course of copper ore, many bunches of copper ore and one of tin. Fig. 3 is a section of the workings on the Crowns Lode at Botallack; the rich bunches of copper ore are ranged in the plane of the lode, and may be regarded as the elements of a great shoot which dips beneath the ocean. As they were not able to sink other shafts to the westward it was decided to sink one great shaft inclined about 32°, following the rich column, while each of the horizontal levels extends into the sterile zones of the lode.

These figures are taken from the Mining and Smelting Magazine, 1862.

Branches.—When a lode becomes divided (splits) it usually loses much of its value, the term *branch* is then applied to those parts which contain enough mineral to pay for working.

In some cases the whole series of branches contain more mineral than the lode itself. The branches pass off both from the *hanging-wall* and the *foot-wall,* sometime they re-unite, at other times they die away in the rocks as joints, occasionally such branches run between two distinct lodes and connect them together.

Sometimes an important branch passing away from the lode at one place joins it again at another, so as to enclose a lenticular mass of the "country." This mass is called a "horse." It is often. traversed by many little metalliferous threads, and very frequently, at some part at least of its junction with the main lode a good deal of mineral is found. These "horses" do not of themselves constitute rich parts, but they are often associated with such. Sometimes they are formed, not by the junction of a lode with one of its branches, but by the coming together of two distinct lodes and the branches common to both; or yet again, by the meeting of different branches of the same lode with a cross-course.

Floors and Carbonas are accessory deposits (*gîtes*). They are sometimes very important, but have only been observed in a few mines.

The Floors are analagous in structure to the "flats" of the lead mines of carboniferous limestone. They are rich branches of tin or copper ore which extend in a nearly horizontal direction to a considerable distance from the lode. The St. Just district presents good examples of floors of oxide of tin and schorl.

The Carbonas are rich masses of tin ore occurring in granite, the true equivalents of the pipe-veins of the North of England. They have been met with at St. Ives Consols and Providence Mines, both in the St. Ives District. Mr. Henwood has described how they are related to the lodes.* The abundant association of schorl with the tin is characteristic here.†

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* Trans. Roy. Geol. Soc. Corn., Vol. V, pp 19-21.

† Deposits of tin ore resembling pipe veins occur at East Wheal Lovell, in Wendron, and were described in a paper read to the Royal Geological Society of Cornwall, in 1875, by Dr. C. Le Neve Foster.. They differ from the St. Ives Carbonas in the absence of schorl.—J.H.C.

Sometimes the rich parts are abruptly terminated, being cut off by a cross-course, a "joint," a "slide," or by a change in the "country;" but under ordinary circumstances "the passage from riches to poverty is rarely abrupt, for at the circumference of a rich mass the country is generally impregnated with patches of mineral, and traversed by thin veins.*

3.—*Remarks upon the general characters of the rich parts.*

The English authors have always noticed with great care those circumstances which most frequently accompany riches in the lodes of Cornwall. These observations, taken at many different times in a great number of mines, may be regarded as the general characters of the rich parts.

Mr. Henwood has summarized these numerous observations so far as they relate to the lodes of tin, copper and lead. I shall have occasion to make use of all his conclusions, but will here reproduce some of them, with a modification of form only.

1. Those parts of the lode whose inclination is most nearly *vertical* are always most productive.

2. In the rich parts the lode is enclosed in a "country" of *moderate hardness.*

3. The "courses" or "shoots" generally dip in the same direction as the "country," and very often also the groups of bunches contained in the same lode.

I shall not here insist upon the lithological characters of the different enclosing rocks, and the mineralogical character of the gangues of different veins, nor of the nature of the different gozzans which indicate each of the metals, tin, copper, or lead; but I shall draw attention to some other remarks, independently of the kind of ore, which have been made upon the mutual influence of junctions of lodes upon each other, and of lodes with their branches, or the joints of the "country;" and upon the relative positions occupied by the rich parts in the nearly parallel lodes of a given district.

In many mines a notable proportion of the riches is connected with the complexity of the rocks and their fractures, whether lodes or cross-courses. Thus, the Cornish mining engineer who has to make a report, however brief, does not fail to state whether the mine is opened in granite alone, in killas alone, or at the junction of granite and killas; whether it is traversed by one or many elvans, and whether any hornblendic or dioritic schists have been met with. Then he mentions what lodes are known, their approximate direction, with the amount and direction of their underlie; and the same of the cross-courses. He states if either of the lodes has been found profitable in its prolongation in an adjacent mine, and whether any parallel lode has been worked upon, and with what result. These elements, combined with local tradition, serve as bases from which the value of the property is estimated. The complexity is not always of the same order; here it is the result of a passage of the lodes from one rock to another, there it is the occurrence of one or more elvans; elsewhere the junction of different lodes is a matter of interest; again, the cross courses are peculiar; finally, in great mines, these local circumstances are often grouped unequally in different quarters.

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* Henwood, Met. Dep., p. 179.

The study of any given mine, even when limited to an examination of the *mechanical element* in its influence upon the form of the rich parts, implies that we have taken into account the phenomena of fracture and the movements of the ground concerned in the preparation and filling of the cavity; in other words that we are aware of the proper direction and relative age of each of the principal movements.

A knowledge of the "stratigraphic systems" of the country enables us to co-ordinate the observations gathered in mines of different districts, and gives powerful aid in separating general characters from particular facts.

In the present work we shall study the elementary phenomena of *an isolated lode in a single containing rock* in a region at some distance from junctions, intersections, or changes of rock. Far from being a mere abstraction, such a lode may constitute a perfect mine, whilst in more complex deposits each lode with its "country" considered separately realizes our idea to some extent.

In such a lode or part of a lode the configuration of the rich parts has a direct relation to the nature of its "country." We shall seek to specify the characters of these rich parts and to distinguish them practically from the more variable riches which upon other parts of the same lode are connected with the local circumstances already enumerated.

We have seen that the rich parts:—

1. Are those most nearly vertical.
2. Are enclosed in rocks of moderate hardness.
3. Dip in the same direction as the country.

To these three general characteristics I now add, as a result of my own observations:—

4. The bearing ("*orientation*") of the rich parts often corresponds to the direction of the stratigraphic system with which the fracturing of the earth in the region in question is connected.

It will be necessary to develope each of these characters in order to determine their meaning and extent. Then, still dealing with the elementary case of a single lode in a single "country," we shall show that the four characters are intimately connected, being the effects of one initial cause; viz.: the fracture of non-homogenous strata consisting of a series of beds of differing qualities.

I. Inclination or Underlie.—The diagram, fig. 1, pl. II, is a vertical cross-section of a lode. The hanging wall is indicated by the line a'b'c'd'e', the footwall by a b c d e. In the nearly horizontal parts a'b c'd the walls are almost in contact, whilst in those more nearly vertical bc bc″ de de″, they are considerably separated.

The fracture is of an undulating character and has been followed at one or more periods by a descent of the hanging wall. This relative depression has produced a series of galleries separated by thin very long pillars. The pillars are the flat and poor parts, the galleries have served as channels for the metalliferous fluids, the depositions from which have converted them into rich parts.

This character, one might almost say this important general law, was recognized by Mr. Richard Thomas, so far back as 1819,* and by Mr. Henwood in 1843. Mr. Henwood observes† that in passing in depth from a flat to a vertical part it is the foot wall which *first* becomes more vertical, the hanging wall retaining its former underlie for some time, the "steepness" and the size of the lode increasing together.

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* On a Survey of the Mineral District between Chacewater and Camborne, p. 20.

† Trans. Roy. Geol. Soc. Corn., Vol. V, p. 231.

This observation on the relative steepness of different parts of the same lode must not be extended to the lodes themselves as a whole. Some productive lodes are worked which are but little inclined from the horizontal; others are poor although strongly inclined. Still, the medium inclination of the principal east and west lodes of Cornwall is about 70°, whilst that of the cross-courses (called north and south lodes when metalliferous) is about 80°. The cross-courses, which are mostly unproductive, have therefore a mean inclination greater than that of the useful lodes.

In a lode we have then to consider, not only the *mean* inclination but still more, the *successive* inclinations of its cross-sections. *Those parts whose inclination approach most nearly to the vertical are always the most productive.*

II. MODERATE HARDNESS —The hardness of a well-developed lode has usually a distinct relation to that of the "country;" and often this latter is a little softer in the immediate neighbourhood of the vein than at a distance of some yards. The price paid for "drivage," after making due allowance for special difficulties or advantages, indicates pretty nearly what is here stated, viz.;—

In Cornwall the rich parts are generally enclosed in rocks of moderate hardness.

Still, it cannot be said that *all* very hard rocks are unproductive, since some greenstones* have been known to contain fine deposits of copper ore. But from a mechanical point of view we may say that a favorable rock is one easy to break but hard enough to remain open without timbering.

In this manner we may summarise and specify for the schists and granite of Cornwall the property of moderate hardness, a property which is elsewhere eminently relative, and which must be properly estimated in each district and each deposit.

Thus, a rock of good hardness for tin is regarded as too hard for copper. Without referring to any particular lode, I would remind my readers of the well-known bad influence of regions which are too hard or too soft. The first are difficult to break, and the second fall too readily, and these differences both tend to poverty.

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* The ironstone or "ire-stone" of the Cornish miner.

Finally, the hardness of the country must be considered irrespective of the modifications due to the chemical action of the mineral springs upon the walls of the lode, such as the decomposition (kaolinisation) of the granite or the silicification of granite or killas.

This character of *moderate hardness* must not be extended without reserve to all mining countries. In Flintshire,[*] for example, the carboniferous formation includes beds of limestone and shale covered by beds of very hard chert, which latter have proved very favourable to the lodes of galena.

From the point of view already indicated we should say the shales were too soft to allow of a cavity remaining open, so that the lode is reduced to a mere joint; the limestone has a good moderate hardness, and an energetic reaction, while the chert though hard is brittle, and in spite of its chemical inertia, has favoured the production of cavities in which the galena has accumulated; to sum up, chert and limestone are easily fractured, and their cavities remain open.

III. Dip (of the courses or shoots). This third character has an importance so great that it appears to me necessary to give many details of the circumstances under which it has been observed, and to reproduce the terms of the statements made by many observers.

In 1836 Mr. Robert Were Fox,[†] quoted the following observations of Captain Richard Tregaskis, "When lodes are nearly at right angles to the (strike of the) beds of killas, the masses of ore which they contain are generally conformable in their underlie (dip) to the direction or dip of such beds; in other words they usually take an oblique direction in the lodes, and form what the miners call *shoots* of ore; and when the directions of the (strike of the) beds and lodes are nearly parallel to each other the ore has not usually any independent dip or *shoot* in a lode; it is then termed a 'pipe' of ore.*

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[*] Gisement du minerai de plomb dans le calcaire carbonifère du Flintshire (*Annales des Mines*, t. XI, p. 351 [1857]). In the North of England, in spite of local differences of composition the Mountain Limestone presents analagous phenomena. At Swaledale in Yorkshire, according to Mr. L. Bradley, the chert is not exclusively silicious but is an intimate mixture of 58 p.c. silica, with 37·5 p,c. carbonate of lime At Alston Moor, in Cumberland, instead of chert there are beds of quartzose sandstone, or freestone. See fig. 5, plate I, from Wallace.

[†] On Mineral Veins, p. 95.

"The large courses of copper ore in killas in the Consolidated Mines, which are so productive at present (1836) underlie in the lode towards the east from the summit of the hill on its eastern side, whereas, the ore which was extracted from the western side of the hill inclined towards the west, the strata or beds of killas having the same dip as the ore in both instances, and it seems from his inquiries that similar coincidences have been observed in other lodes, in the United Mines, Huel Unity, Huel Caroline in Perran-Uthnoe, &c. &c.

"When lodes cross the lines of junction of granite and killas, the masses of ore are usually conformable to their direction, and this happens if the ore be included either in the granite or in the killas, and it very frequently is confined almost exclusively to one of these rocks.

"It does not, however, seem to follow that other masses or shoots of ore in the same lodes further to the eastward or westward of the lines of junction are parallel to the direction of the ore at or near the junctions; on the contrary, they not uncommonly dip in opposite directions......as at Huel Jewel, Huel Gorland, Huel Friendship, &c."

Briefly, observes Mr. Fox, Captain Tregaskis "seems to think that shoots often conform in their directions, in some degree, to the inclination of the ground."†

In 1843 Mr. Henwood wrote "The position and configuration of the granite masses seem to exercise an influence on the disposition or arrangement of ores contained not only in the *lodes* which occur in that rock itself but also in those which traverse the slates adjacent thereto; for the masses or *shoots* of ore in any given *lode* have, generally speaking, a prevailing dip, and whether they occur in granite or in slate, whether on the eastern or the western side of the granitic tracts, this inclination is invariably towards the great body of the slate."*

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* This expression, "pipe of ore," is very little used; if the length is considerable such a rich zone is called a "course" of ore.

† Rep. Roy. Corn. Polytech. Soc., 1836, p. 96.

He further quotes from a previously published paper of his own,† "This view of the disposition of *shoots* of ore embraces those which are found in the granite as well as those occurring in the slate series. It therefore includes that of Mr. Tregaskis, which has subsequently been quoted by Mr. R. W. Fox."‡

In 1859 Captain Chas. Thomas referred to the preceding remark in the following terms, "Mr. Henwood says the *courses* of ore which occur in the granite, or in the argillaceous or hornblendic schists in the neighbourhood of the granite dip almost always *from* the granite; this is generally so, but I have observed some opposite examples."

The principal mines of Cornwall being opened near the margin of the granite masses, the application of this character is very easy, and we may either say, as he expresses it, that the rich parts dip *towards the great mass of the schists*, or according to the expression of Mr. Charles Thomas, *away from the granite.*

This character extends itself with the necessary modifications to mineral districts in which there are no granitic bosses. As early as 1848 Mr. Warington Smyth, in describing the lead district of Cardigan and Montgomery wrote, "In many cases the productive portions are observed to be more continuous in a vertical than in an horizontal range, and to incline somewhat westward in the descent. It might sometimes be inferred that the "shoots" of ore, as they are termed by the miner, run parallel to the beds of rock, and thus accompany those strata whose composition has been most favorable to the deposition of metallic matters; but the fact is far from being generally established, and they would rather appear to conform to the dip of the planes of cleavage, if we look at the persistence of the westerly dip in some instances where the beds are inclined in the opposite direction."* I shall give other extracts from this very interesting memoir.

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* Met. Dep., 193-4.

† Edin. New Phil. Jour., XXII, p. 157.

‡ In 1871, in his "Address," Mr. Henwood said "Most courses have within their respective lodes an endlong dip or shoot which usually approximates to the contour and *bedding* of the neighbouring granite (according to Messrs. Carne, Boase, Henwood, and De la Beche) and to the inclination of the cleavage planes in the adjacent slates (according to Messrs. Fox and De la Beche.)—Rep. Miners Assoc. Corn. and Dev., 1872, p. 11.

In 1860 I visited the Lisburne Mines,† and those of Cwm Ystwith, which are reckoned among the best in Cardiganshire, where I recognized the characters observed by Mr. Smyth.

In 1862‡ I described the *shoots of ore* in the great lead lode of Snailbeach in Shropshire, The "country" is a silurian schist (Llandeilo beds). The strike of the beds is 22° east of north, corresponding with the system of the Longmynd; they dip to the W.N.W. at an angle of about 60°; the mean direction of the lode is distinctly east and west, but there are some great inflexions or "turns." It dips 62° to the southward. The intersection of the beds of schist by the lode, gives, according to the direction of this latter, lines of intersection inclined from 45° to 55° from the horizon, which is precisely the dip of the rich columns westward. They had discovered in 1860 six principal shoots, of which one had an horizontal length of 150 yards. Fig. 4, pl. I is a reduced section of a part of the lode.

Without multiplying examples, I will return to the lodes of Cornwall: and I thus formulate the foregoing remarks, which apply to all the lodes, whether opened in schistose strata or in beds ("*bancs*") of ancient granite.

The metalliferous bands or zones often dip in the same direction as the enclosing rocks.

IV. Proper Bearing.—The English authors have paid great attention to the proper "bearing" of the lodes, and the miners attach much importance, not only to their mean direction but also to their deviations or inflexions.

Captain Chas. Thomas especially has observed and recorded the intimate relation which exists between the bearing of a lode and its riches; he has shewn clearly that if it is important to observe the mean direction of a lode, the miner should still more carefully observe its successive variations of direction, and their influence upon the value of the different parts of the deposit.

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* On the Mining District of Cardiganshire and Montgomeryshire. Memoirs of the Geol. Survey of Great Britain, Vol. II, pt. 2, p. 667.

† Annales des Mines, 6e serie, t. IX (1866) p. 10.

‡ Ibid., t. I, p. 446 (1862).

The following extract from his lectures leave no doubt as to the opinions of Capt. Chas. Thomas upon these points; "all lodes are subject to great variations in their direction and size, and where these vary the composition and general appearances usually undergo a corresponding change."*

To illustrate his remarks, Mr. Thomas gives a plan of many levels opened upon different lodes in the cupriferous zone of Dolcoath Mine, distinguishing the rich parts from those which are simply mineralized, and these again from the parts altogether barren. Upon this plan he has written "*Changes in the bearings of the lodes appear to be the chief cause of productiveness or otherwise.*"†

We see, then, that Captain Thomas was not content to observe the *mean* directions of the tin, copper, and lead lodes in Cornwall, but he also noticed the direction of each part of each lode. Accordingly, the *useful angles* which he has indicated for each of these three metals include pretty accurately the mean directions of the productive lodes, but still more they limit the *groups of bearings* which correspond to the rich parts.

Thus, we read "It is important to observe that the direction of a lode through a mine taken from the east and west extremities may greatly exceed ten degrees north of east and yet the mine be a rich one; but it will be found on examination that intervening portions of the lode are in the right direction, *and from those portions its riches are derived.*"‡ Again, I have found in numberless instances a rich course of copper ore while the direction of the lode was south of east, due east, or five degrees north of east, but a turn in the lode taking place of five to seven degrees further north, the lode would not pay for working."*

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* Remarks on the Geology of Cornwall and Devon, 1859.

† The directions given by Mr. Henwood will be made use of in our consideration of the different districts, but they do not give the details of each lode.

On this point Mr. Chas. Thomas says on page 25, "Mr. W. Jory Henwood in his report of the two hundred mines of Cornwall and Devon has given the bearings of nearly all the lodes which he inspected. He, however, took only the *general bearing* of the lode from one end of the lode to the other, overlooking the variations between the productive and unproductive parts. By this omission he not only lost a fine opportunity of accumulating many important facts, but the whole subject of *bearings*, by his mode of statement, has a direct tendency to mislead. Taking his report for a guide, the bearing would be no indication whatever of productiveness or otherwise; his rich lodes as as well as poor being found under almost every variation of direction. In reference to the productive *parts* of lodes there is no such confusion, order is all but universal—exceptions, if any, are rare indeed, and then of limited extent.

‡ Ibid., p. 26.

The practice in Cornwall is to open the lodes by levels driven along them about 10 fathoms apart; sometimes these 10 fathoms are reckoned vertically, sometimes on the underlie of the lode.

Each level is named according to its depth in fathoms below the water level or *adit.*

The shafts are usually vertical in the upper part of the mine, and afterwards inclined, following the underlie of the lode, and wherever possible in one of its productive parts.

The plans of the mine generally include a horizontal projection of the levels or true "plan," and a series of longitudinal sections shewing the workings on each lode. In some mines there are, in addition, cross-sections shewing the underlie of the lodes.

Upon the longitudinal sections the levels are drawn in parallel lines. The parts removed between the levels ("stopes"), are also indicated, the rich parts being colored as they are removed, so that their form and situation in the plane of the lode are conveniently shewn. The thickness, of the lode is of course, not shewn in the "longitudinal section."

The plan of a mine in which there are many lodes and cross-courses, and which has a depth of more than 200 fathoms, is generally overcharged with lines, especially when the lodes have but little underlie. In the plan the levels alone are marked, and not the stopes which have been worked away.

The *median surface* of each lode is pretty well indicated by the plans of its equidistant levels, which correspond somewhat to the contour lines used in topography. Supposing this surface to be perfectly known, undulating, and departing sensibly from what might be termed the mean plane of the lode, a series of equidistant horizontal sections would indicate each of these variations by their curved and straight portions.

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* Remarks on the Geology of Cornwall and Devon, pp. 5, 6. He indicates certain "best directions" for the three metals, as follows:—

For Tin Lodes............30° N of E to 30° S of E
,, Copper Lodes ......10° N of E to 50° S of E
,, Lead Lodes.........10° W of N to 40° E of N
Best Lodes 5° N of E to 25° S of E
All bearings "Magnetic" (1859).

It is this *horizontal of the mean plane* which we will call the mean direction of the lode. The curved lines, sometimes very different in parts, will almost always differ a little from the lines of the respective levels. The reason is that the levels are not exactly horizontal, but descend a little towards the shafts from which they were driven.* Again, they are not always driven exactly in the same part of the lode, and in passing from the foot wall to the hanging wall of a tolerably large lode, the plan of the level would be sensibly inflected, although there might be no inflexion of the walls themselves; finally, the levels may be driven at different depths upon distinct branches.†

Precise observations on bearings can only be made in the workings themselves, and upon those parts which are straight, generally upon the foot wall which is exposed by the openings and workings.

Bearing in mind these remarks, an examination of an exact plan of the workings gives a very sufficient idea of the form of the deposit, and enables us to recognize the variations of bearing of the lode, and to appreciate their importance. Let us consider a plan of a level from this point of view.

It exhibits in general a series of almost rectilinear elements joined together by curves, a sort of broken line with rounded angles. The acute angle formed by any one element, and the prolongation of its neighbour, is often 4°, 5°, or 7°; it sometimes reaches 10°, 12°, or 15°, but only exceeds this latter in special cases.

The relative lengths of the successive elements vary much in different mines (Fig. 2 and 3, pl. II), and their absolute length not less so; they are often 20, 40, or 60 yards, sometimes much less, but rarely more than 100 or 150 yards.

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* The miner constantly tends to rise in going forward: the use of little subterranean tramways in modern mines obliges him to maintain a regular floor to the "level," and secures at the same time an outward flow of water. The slope of the levels is about ⅓ to ½ an inch per fathom, but in ancient works the "levels" often rise much more than this.

† Two levels ("ends") having been driven each to a considerable distance from a shaft or winze, it is often necessary to make a communication between them (i.e., for the sake of ventilation). This is done by "sinking" from one and "rising" from the other, so as to meet half way; by this means the miners often discover that they have been working on distinct branches of the lode, notwithstanding which they continue to drive each end upon its original branch.

The deviations we have thus described are called "turns" or "warps," this latter term being generally applied to a small but rather abrupt bend, the former to a more gentle but longer bend.*

In some lodes, after a portion distinctly sinuous, the mean direction becomes sensibly changed, and turns 15°, 20°, 25°, or even 30°; the plan of the level in this new region oscillates around this second mean direction just as in the former case. Farther on the lode may return by an equal but contrary detour to a direction parallel to its original course.

Briefly, the plan of a level is of two kinds:—

1st.—An undulating but almost straight line of such a character that if we join a point A (Fig 2, 3, Pl. II) to the extremities B and C of a tolerably distant rectilinear "element," the side A B may be taken as a mean direction.

2nd.—A line of great inflexions (fig. 4) composed of large undulating "elements," each of which may be taken as a line of the first kind, having its own mean direction pretty well defined.†

It is easy to see that the first case is that of lodes in which the initial fissure is connected with a single system of fracture, whilst in the second case the opening is due to the action of several systems of variable powers, which having acted at more or less distant epochs, have prepared and developed a complex fracture. From a practical point of view the deposit still constitutes a single lode for the miner in search of ore, but to the geologist it is the result of a series of components, parts of which are presented in the large successive "elements. To study the formation of each of these elements, to distinguish their rich and poor parts, to seek the origin of their deviations, their direction and extent, both angular and longitudinal—these must be our aims, since we shall thus be able to understand the first case in its entirety, and the second in its different parts.

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* The sinuosities of the levels are more or less observable, not only in the different lodes of Cornwall, but also in other mining countries. Mr. W. Smyth says of the lodes of Cardiganshire (in the work already quoted p. 659), "Their direction.........is subject to repeated variations, and at such short distances that some of the veins of less importance when drawn on a large scale, appear like zig-zag lines This is especially the case when the beds frequently change their nature.

† M. Rivot in his Memoir on the Lodes of *Vialas* (*Annales des Mines*, 6th series, vol. iv, 1863) has given a plan of the Solberge level or second level of the old lode between the Bosviel and the first cross-course,—an interval of about 150 yards. which shews successively the following mean bearings, viz.: 105°, 135°, 105°, 90°, and 105° E of N, or according to the German term: *horas* ("*7, 9, 7, 6* and *7* o'clock.")

Limiting in this way our field of observation, let us see how a series of successive and vertically equidistant levels appear on the plane of projection or "plan."

The diagram Fig. 5, Pl. II, represents a series of levels opened 10 fathoms apart in a lode bearing nearly E.N.E., and underlying to the south; the thick lines indicate the rich parts, the thin lines the poor parts; it will be seen that there are two *shoots* A, B, and three unproductive zones C, D, and E.

In passing through the *shoots* it will be seen that the projections of the levels are closer together than in the poor parts, this is a direct consequence of the first character, viz.,—that the rich parts of a vein are always those most nearly vertical. We see further that the levels are *straiter* in the rich than in the poor parts, and that the bearings of the two rich parts A and B are precisely the same. Experience shews clearly that this *proper bearing (bonne orientation)* is common to all the rich parts which are met with in following a lode or portion of a lode which is nearly rectilinear, so long as it is under the conditions already specified, viz.,—a single lode in a single containing rock.

Repeated observations have enabled me to ascertain that this direction is *exactly* or *very nearly* that of the Stratigraphic system with which the initial fracture of the lode or portion of a lode is connected.

The poor parts on the contrary do not affect any particular direction, in fact they correspond to the variations of 4°, 5°, 7°, 10°, 12°, or 15° already referred to—true *deviations* imposed upon the fracture. We shall shew farther on that they are due to a want of homogenity of the country, and depend upon the physical properties and the relative position (strike and dip) of the encasing strata.

At present we close with a general announcement, that of our fourth character, viz.,—*the bearing of the rich parts is generally that of the Stratigraphic system with which the initial fracture of the lode in the region under observation is connected.*

IV.—*The mutual relations of the four general characters.*

I have never met with a single experienced Captain in Cornwall who has not observed, more or less, some of the characters we have above described; but, according to the nature of the rocks and lodes in the mine under his management, each has been unequally impressed by their importance, and especially attached to that or those which were most apparent in the workings under his control.

Moreover, the natural attention to local characters, such as the aspect and color of the "country," the mineral properties of the ore and veinstone in the different parts of the lode, the phenomena of junctions of rocks, lodes, or cross-veins, &c., makes it often difficult for the miner whose field of observation is rich, but confined to a few mines, to employ with prudence the qualification *general*.

Thanks to the labors of English observers, this term may be safely applied to the characters we have specified. I believe they are *absolute* in the elementary case of an isolated lode in a single stratum—in other words, that they are so intimately related to each other, that a certain observation of one ensures the recognition of the three others: they determine the form and position of the *rich parts of a given lode in a given stratum.*

Such rich parts constitute what we may call *normal riches*, the term *accessory riches* is applied to those whose formation has been especially influenced by complex circumstances, the study of which we will postpone.

Some explanations are necessary to establish the justice and utility of this classification.

From the time of the first fissure to the present, every mineral deposit has been constantly under the influence of those physical and chemical forces by which it was originally formed, or has since been developed and modified.

However, it is reasonable to suppose that at some particular epoch the useful substances ceased to arrive in the lode, and by remaining there to increase its value, either because the general conditions of the deposit did not favor the deposition of mineral, or because the mineral fluids had ceased to circulate or had been dried up, or that the subterranean channels had become gradually filled up. At that moment we may say the lode was formed. What has since happened can only be spoken of as accidental, or as alteration.

Before that time, on the contrary, all the phenomena were connected with its formation, so that the miner has no more reason to complain of the cross-course which "cuts out" his ore, than of the hard or poor band which limits the rich shoot; without the solid pillar there could have been no favorable channel, and often but for the cross-course, the treasure of which he regrets the interruption would have been very small.

Assuredly normal riches do not escape those local circumstances which give to each mine its special character, and which sometimes give their preponderance to the accessory riches; but *if the extent and continuity of the normal rich parts are somewhat* modified, their essential conditions of form and position are the direct consequences of the relations of the lode and the stratum.

It is important to the miner to distinguish them, for he can to some extent reckon upon their prolongation and recurrence; by them especially he recognises the *mineral aptitudes* of each lode, and is better prepared for the difficult study of junctions and cross-veins.

If this classification of rich parts into two groups—of normal and accessory—is found to be useful, we may now sum up the diagnostics of each group.

The four general characters are absolute for *normal* rich parts; while they *may* apply—one or more—to the *accessory* rich parts: it is because they very frequently accompany these latter that they have attracted the attention of observers, and have been recorded; the distinction, we think it proper to establish, however, has not been previously made. On the other hand, as they fail to apply to certain accessory riches, the observers should have multiplied the exceptions to each of their general rules.

A few examples will suffice to define these ideas.

A more or less inclined rich band may constitute an accessory rich part:—

1st.—If it occurs at the junction of two encasing rocks of different nature, such as (*a*) granite and killas, (*b*) killas and elvan, &c.

2nd.—Or if due to the junction or intersection of the lode with or by another lode.

3rd.—Or to the intersection of the lode by a cross-course.

Let us see if, and how, we may still apply each one of the general characters.

The third character (dip in the same direction as the stratum) exists in the first case (1*a*)—it may or may not exist in the others, according to the relative conditions of the dyke of elvan, the second lode, or the cross-course.

The second character (moderate hardness or special quality of the enclosing rock) is only relative. The mineral may be found in certain quantities enclosed by rocks which at other parts of the mine are regarded as little favorable.

The first character (underlie) is much more generally applicable, for although certain accessory riches will be found to lay almost horizontal, it is not less true that the parts nearest the vertical are still generally the best.

Finally the fourth character (good bearing) fails to apply to the accessory riches more often than the others, and becomes, in consequence, a valuable test. We have seen that many captains —and we believe Capt. Chas. Thomas at their head—have already recognised the importance of "proper bearing" in considering, without our classification, each of the rich parts of the lode. Still more, an experienced miner may, in works largely opened, succeed in determining within a few degrees the common bearing of the normal rich parts. If similar observations are made upon different lodes belonging to the same system of fracture, the bearings obtained differ very little from the bearing of the system calculated for that district.

A normal rich part has a good direction (IV)—an inclination nearer to the vertical than other parts (I), is enclosed by rocks of moderate hardness (II), and dips in accordance with the inclination of the strata (III). Moderate hardness is a property of certain beds of the enclosing rocks, and consequently it is where the lodes traverse such beds that they are best developed. Favourable or good beds will alternate with bad ones; the former enclose the normal rich parts, and it is natural therefore that these rich parts (courses, shoots, series of bunches, &c.) should dip in the same direction as the containing rocks. The major axes of the normal rich parts will be therefore parallel to the intersection of the median plain of the lode, with the planes of the beds.*

A normal rich part is therefore enclosed in a good bed; it remains to determine why such favorable beds should be fractured more vertically than others, and more in accordance with the bearing or orientation of the Stratigraphic system.

To indicate our meaning more accurately, we will take a kind of medium example from Cornwall, reserving extreme cases for future discussion.

The "country" consists of ancient schists of which the beds are only moderately inclined—say from 20° to 40° from the horizontal.

The upheaval does not appear to have been violent, as the inclination of the beds is not accompanied by any such violent phenomena as reversals of strata, great contortions or dislocacations, but simply by such fissures and joints as were inevitable. Let us suppose that there was a tendency to fracture along a line, making with the direction of the beds an angle of 20° to 40°, or too great to allow of a simple re-opening of the joints of the rocks. The beds were alternately of moderate hardness and very hard, the latter being very fissile.

Finally, we will suppose that at the time of the production of the fissure, the opening was extended by the descent of the hanging wall—a fact directly in accordance with the first general character.

The diagrams, figs. 6 and 7, plate II, are two sections of which one is vertical and at right angles to the beds; the other is horizontal. The good beds b_1 b_2, and the bad beds m_1, m_2, m_3, are drawn of equal thickness, their inclination (i)=35°, the direction, according to which the fissures tend to extend themselves, makes an angle (a)of 32° with the strike of the beds. I have represented two natural cases—the lodes Fc dipping in a direction contrary to the country, Fa dipping with the country, i.e., in the same direction.

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* The favorable beds—whether limestone or chert—in the lead mines of the Mountain Limestone, and the masses of amygdaloidal trap of the copper mines of Lake Superior (M. Rivot, Ann. des Mines, 1855, 1856) enclose the rich parts: it follows, therefore, that these parts dip with the strata. It is a similar phenomenon in the ancient schists and even in the granites of Cornwall, which are remarkable for their bedding, that I am here stating. It has been more difficult to recognise, because the beds—whether good or bad—do not offer such very distinct differences, and especially because the surroundings of the accessory riches add to the complexity of the deposits.

The mean dip of each lode is about 70°.

The rupture of the rocks has been effected under the influence of vertical forces acting along a line corresponding to the stratigraphic System. The direction and the mean angle of inclination are, for each lode, the results of a set of circumstances to which we shall soon return; but accepting the dip or underlie as being due to natural causes, we may say that the lodes Fc have been engendered by a simple rupture of the beds, whilst the lodes Fa are associated with both rupture and separation of the beds. We will now examine each of these groups.

LODES, Fc.—The hard beds m_1, m_2, m_3, being difficult to break, have been fractured almost normally, i.e., according to the plane of least resistance. The good beds b_1 b_2 have more readily submitted to the action of gravity, and the fissure consequently approaches the vertical. If we suppose the fissure exactly vertical, all the levels opened upon this part of the lode would be represented by a single line in the plan of the mine, the bearing of which would be exactly that of the system in action.

The intersection of this vertical plane with the surface of the bad bed is inclined to the horizontal, and this, with the normal to the beds, determines the plane towards which the fissure is inflected while passing through the hard bed.

In this bad region, the levels will be projected in the plan of the mine, in parallels to the direction of the normal plane. Our hypothesis is exemplified in many lodes, and we may affirm that in every case the good beds are broken in a plane approaching the vertical, and whose bearing is in accordance with that of the acting system, while the bad beds are broken somewhat according to the normal plane which we have defined.

If the hanging wall of the fissure could be removed we should see the foot wall composed of a series of steps or ridges, inclined according to the intersection of the median plane of the lode with the plane of the beds. These ridges indicate the variations of direction and underlie.

In one part equidistant horizontal sections give, when projected, traces analagous to figure 5, where the rich parts of the level are parallel, near to each other, and of good bearing, while the poor parts are further apart and deviate in some degree from this proper bearing.

Again, a vertical section across the lode shews how the mean dip is reproduced between the ridges, *i.e.*, between the rich and poor parts.

Thus, the four general characters applicable to the normal rich parts of lodes Fc are found to be intimately related.

LODES Fa.—The relatively easy fissuring of the good beds will be as in the former case near to the vertical, and of proper bearing; but the hard and fissile beds will be crossed by a series of unequal steps, as shewn in fig. 8, the result being a greater general inclination, because the fracture is alternately between and across the thin plates, taking alternately the two directions of least resistance. The "tread" of these steps almost exactly corresponds with the stratification and the "risers" are more or less normal; In relative dimensions the former predominate.

Thus, the *deviation* produces itself in the direction of the "strike" of the beds.

We may find some mineral in the little irregular spaces r, s, t, u, v (fig 8). These little "squats" scattered in the neighbourhood of a level in a poor zone, do not deceive the miner, for the vein is still flat, and the step-like character of the hanging wall is well known as an unfavorable sign.

With the differences just noted, the projections of the levels still exhibit the rich parts more nearly parallel, nearer together and of better bearing, the poor parts deviating from the true bearing and farther apart, whilst the cross-section of the lode shews the ridges.

Fig. 7 (section on CD., fig. 6) represents one level of each of the lodes Fc, Fa. In the good beds the rich parts of each lode have the same bearing, but in the bad beds the level Fc deviates *towards the perpendicular* of the beds, while Fa is deflected *towards their strike*. The mean directions of the two lodes make a very acute angle, the bisection of which scarcely differs from the bearing of the system of fracture, while the intersection of their mean planes dips in the same direction as the beds. We shall refer again to these properties and to their interesting consequences.

Thus, whatever the direction of dip may be, we see that strata of good quality are generally fractured more nearly to the vertical, and more in accordance with the bearing of the system of fracture than the bad ones, and *good strata* are those which contain the normal riches.

The four general characters, therefore, are clearly the results of one single phenomenon, viz ,—the fracture of strata of different qualities by forces acting along a straight line parallel to a given system; and *these characters determine the conditions of the normal rich parts in the deposit.*

CHAPTER II.

SUMMARISING the ideas presented in the preceding chapter, we may observe that the rich parts of the Lodes of Cornwall appear in different forms, and have therefore received different names.

Among those characters which belong to them generally, and are independant of the kind of metal, four, are particularly important.

The riches may be conveniently classed under two heads—*normal* and *accessory* rich parts.

The form and position of the normal rich parts are directly connected with the original mode of fracture, and the four general characters are absolute as far as they are concerned. It is interesting to observe in each system of fracture, the two natural groups of cracks, Fc underlying *across*, Fa in the same direction as the beds.

The general conditions ("allures") of these openings in any given rock, depend very much upon the "angular elements" *i.a.*, where (i)=dip of the strata and (a)=angle included between the strike of the strata, and the direction of the system to which the initial fracture is due.

If the miners of Cornwall accept these propositions, and constrain themselves to observe the direction of the lodes in their normal rich portions, they will gather from the many small variations a true mean for each lode or series of parallel lodes, which will scarcely differ from the orientation of the system of fracture.

The fourth character being verified by a great number of practical observers, merits their confidence in the same degree as the three others.

In this second chapter, we shall study the probable modes whereby the subterranean channels which now compose the normal rich parts have been formed, and we shall use our former conclusions in framing certain hypotheses. From a mechanical point of view, we shall examine the production of the original fissures; the re-openings of the fissures by the descent of the hanging wall; the general conditions of the lodes of both classes; and those of the cross-courses, whether metalliferous or not; and we shall conclude by studying the characters common to those lodes which are nearly parallel.

It is, however, necessary to take account of chemical phenomena also, since they have often modified not only the nature but the very form of the walls.

I.—*General Considerations.*

a. The principal physical and chemical causes which seem to have presided over the deposition of Minerals in lodes.

During certain geologic periods, the mineral solutions flowing in their subterranean channels have varied at different points and different times; and to these variations the deposits of mineral are due.

The two primary causes of these variations—which are otherwise intimately connected—seem to be changes of pressure and chemical reactions.

At a given point, a change of temperature or pressure might be produced for example:—

a.—By changes of level due to movements of the ground, and especially by slow oscillatory vertical motions.

b.—By the growth of the deposits preventing free circulation, and producing a kind of localized laboratory action, as in a closed vessel.

c.—From the movement of the walls upon each other, and the falls of material which might partially obstruct or re-establish the communication with the surrounding sources of supply.

d.—From the greater or less facility with which the ever varying fluids were able to circulate in the cracks, joints, and pores of the rock; or to act upon it physically or chemically. As a consequence of this capillary circulation, the pressure might in some cases be quite independent of the actual depth, or at least, not proportionate to it.

e.—From the reactions between different fluids producing deposits at a given point whenever the general conditions were favourable.

f.—From the action of the fluids upon the walls, or the contents of the cavities. The sides of the cavity may have been simply the country rock itself; or that same rock much altered by decomposition or incrustation; while the walls may have been already invested by earthy or metallic layers. The reactions seem to have been manifested in the highest degree in the *floors* and *carbonas* of Cornwall.* Attacked by certain stanniferous waters, the granite rock has given up to them those elements which were needed to saturate the solvent fluids and to precipitate and fix the oxide of tin; while the gangues which abound especially in tourmaline (schorl) were being produced by the corrosion and metamorphosis of the "country."

A comparison of these stanniferous *carbonas* with the *pipe veins* of the mines of the north of England, seems justified as much by their common mode of origin, as by the analogy of their surroundings. The fluids have passed from the neighbouring veins into the smallest fissures and joints, by preference where those joints cross each other. This attack of the rock having once commenced, the deposit seems to have gathered material to itself, step by step, by a kind of accretion.

The chemical energy of the walls is still more evident in those lodes which are inclosed by bands of rock of greatly different nature. It would seem that certain bands have at times arrested the passage of the greatest part, if not the whole, of the useful metals. Elsewhere the consequences of these reactions are evident, even in rocks not easily attacked. The highly concentrated solutions arising in channels, the walls of which are inert, produce under the influence of physical conditions, deposits which might not have been formed but for the previous saturation of the waters.

Other causes concur in the production of deposits. Among such *terrestrial magnetism* and *voltaic electricity* have attracted the attention of the Cornish Scientists. We owe to Mr. R. W. Fox some remarkable experiments on and theories of the electro-magnetic phenomena of lodes.

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* Henwood, Met. Dep., p 19-21. Address, p 13. H. C. Salmon, Mining and Smelting Magazine, Vol. III, p 138.

The special properties of the *gossans*, the evident and more or less complete transformations undergone by certain minerals, the pseudomorphs which characterise the re-solution of minerals, result from causes which are not purely mechanical, and which are still making themselves felt with variable intensity.

b. Formation of the initial fissures.—Fc. Fa.

During every geological period devoted to the formation of a sedimentary rock, a corresponding terrestrial zone remains under the influence of the *System of Upheaval* proper to that period and zone; that is, the displacements of the ground have a constant *tendency* towards an *orientation* determined by the *System* and its parallels.

The final results of these movements is a *mean depression* in one region and a relative or absolute *upheaval* in a corresponding region. In many cases these undulating movements correspond to slow oscillations with accompanying fractures.

Some high chains of mountains testify to the violence of these phenomena in certain parts of the zone of action of a *System* of upheaval. At the same time, parallel to the axis of elevation, and at no great distance, are great faults and disturbances, with variations, foldings, or even reversals of the strata; the more distant bands are less violently disturbed. At the foot of the chain these vast undulations have given rise to successive steps, (*gradins*) which become smaller as they are more distant from the axis of movement, and more fit to produce fissures, depressions, and gradual downthrows, favourable for the formation of metalliferous channels.*

Cornwall, although fissured through long periods has happily escaped these more violent movements. Its abrupt cliffs of 300 feet high and its hills of granite crowned with picturesque tors and druidical monuments; its valleys and their little streams, and its raised beaches bear evident traces of the movements which it has undergone; but it has neither Alps nor Pyrenees.

From the Isles of Scilly to Dartmoor there are six principal granite masses. Applying a tangent plane to these masses, which indicate the granitic skeleton of the peninsula, we obtain a slope descending to the ocean towards the west-south-west.

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* Thus M. Rivot has identified in the lodes of Lozère, the 8 to 9 o'clock lodes with the System of the Pyrénées, 3 o'clock with that of the Western Alps, and 6 o'clock with the Principal Alps.

Without dwelling upon the peculiarities of the junctions of the granite and killas, I will remind my reader that generally the beds of schist rest upon the granite bosses, and envelope them like a mantle; the line of junction forms an angle of 20° to 45° with the horizon, the laminæ of the schists dip *away from* the granite but less rapidly than the surface of contact.* This may be summarised by saying that the uptilting of the schists is due to the upheaval of the granite.

The diagram fig. I. plate III. is a double vertical section N. and S. intended to represent the effects of an upheaval of the granite in Cornwall in its different stages. The *System of Upheaval* is supposed to be E.W.

The line *s.b.m.d.* indicates the (hypothetical) profile which would result from an upheaval unaccompanied by a partial depression. The upper section applies to the first phase of the phenomenon; the granite is slowly elevated in an anticlinal ridge, and the schist upon its northern flank is elevated with it; but at some little distance there is a tendency to form a synclinal trough, both being parallel to the *System.* Under the influence of gravity a series of fissures is produced in the northern region between *n.* and *d.* which dip north, these are followed by a depression of the rocks caused by the gradual descent of the hanging wall upon the foot-wall.

During the formation of these fissures others are formed to the south by the strain occasioned by the elevation of the granite. These fissures shewn between *s.* and *m.* are more or less at right angles to the curve of the rocks, consequently they dip to the south; their walls open a little but there is little or no slipping because the upheaval continues little by little until it attains the position of greatest elevation *s.b.*

Towards the end of this period the fissures Fa. extend into the inflected part *d.m.b.*

The second phase or period of reaction, characterized by the partial depression of the granite, may be followed upon the lower section.

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* Henwood—address, p. 2.

There is no longer a movement of the schists, and we will suppose them relatively at rest in the neighbourhood of n'. The fissures which had previously been produced in the region *s.m.* actually yield by the descent of their hanging walls, and become more or less open cracks, Fc., while new fissures are produced from *m.* to *d.* or even beyond.

Meanwhile a series of triangular prisms is produced in the region *b.m.d.* by the opening of a great number of secondary fissures, many of which have a greater underlie than the primary fissures, and so form junctions with them.*

Besides those fissures and openings whose bearing is very nearly that of the System, there must be others whose direction is at right angles; no zone of any considerable length could be elevated or depressed without meeting with interruptions perpendicular to its axis.

Besides those fractures which are developed into openings by the descent of the hanging wall—or which remain in the condition of mere fissures, simple joints are often produced in both directions at right angles, and variable in number and extent.

Still later, another system of upheaval, whose orientation makes with the former an angle of 15°, 25°, 30°, 45°, has taken place in the already fractured and fissured region, producing analagous phenomena, and subject to the change of direction and local circumstances, it either intersects the ground with new fissures or is absorbed by the movements of the rocks on either side of the previously formed fissures and openings.

In the rich districts of Central Cornwall we recognise five distinct east and west Systems, whose bearings have a total divergence of not more than 45°. These are the system of Finistère, Westmoreland, Land's End, Ballons and Pays-Bas.

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* Highburrow and Martin's Lodes at Tincroft Mine, near Redruth, seem to illustrate this kind of phenomenon. See Henwood, Met. Dep. Tab. L II. and fig. 2 . pl. VI. The killas dips to the North at an angle of 10° to 20°. Highburrow lode bears E. 25° N. and dips southward about 70°. Martin's lode bears E. 18° N. and dips northward for 50° to 60°. The junction occurs in the west part of the mine at a depth of 84 fathoms, and in the eastern part at a depth of 158 fathoms. After meeting with Highburrow lode, Martin's lode continues with it, adopting its direction and underlie.

To them is due the complexity and in great part the richness of the metalliferous deposits.

Thus then, we have during the first phase or upheaval of the granite, the formation of the fissures Fc., and fissures and openings Fa., with a descent of the hanging walls of these latter.

In the second stage or partial depression of the granite—a descent of the hanging walls and re-opening of the fissures Fc. already formed; the formation of a new set of openings Fa., and a relative descent of their hanging walls; the production of secondary fissures and openings Fc. and Fa. especially in the zone of inflexion, and also by a subdivision of the prisms already formed, which give way under the action of gravity. The re-opening of these fissures results again in the depression of the hanging wall. The second will complete for the openings Fc. the effects of the first, for "the veins, whether lodes or cross-courses, dip much more frequently *towards* than *from* the granite,"* The final result may be thus expressed. *The lodes Fc. which dip across the beds of rock predominate.*

II.—*General Characters of the Rocks and Lodes of Cornwall.*

We have in the first chapter for studying the formation of channelled fissures (both Fc. and Fa.), selected an example which includes all the ordinary circumstances as they are observed in Cornwall.

Before treating this subject more in detail, it is necessary to specify the mean conditions or characters of the county. We shall only touch incidentally upon its general geology or the lithologic characters of its rocks. It will be sufficient to take note of their principal physical properties and to indicate their surroundings, whether beds of killas or masses of granite.

The inclination (*i*) of the encasing rock, the mean underlie (*p*) of the lode, (whether Fc. or Fa.) and the angle (*a*) comprised between the strike of the strata and that of the system of fracture —these are the elements of which we shall study the influence upon the formation of the lode.

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* Henwood: Address, p. 6.

As a contrast we shall summarise the analagous characters of two other English Mining districts.

It has long been known that the three metals, tin, copper, and lead, the principal products of Cornwall, occupy three concentric zones in relation to the granite. Tin occurs in the interior zone, beyond that the copper, while the lead is only found at some distance from the granite. The extension of mining near the surface and in depth has but confirmed this ancient notion. As a general formula its accuracy is unquestionable. Capt. Charles Thomas[*] has mentioned the occurrence of two distinct kinds of granite in the granite masses. He calls one *primitive*, the other secondary; for these terms I would substitute the terms Quarry granite and Mine granite.

The first is practically a sort of "farewell rock," not necessarily for the fissures themselves, but for their mineral riches.[†] It forms the principal summits and undulating plateaux or *moors*.

The mine-granite on the contrary occurs at the flanks of the masses and in depressions at the foot of or surrounding the high hills.

It may be useful to compare these facts with those observed in the centre of France by the authors of the Carte Géologique.[‡] The gneiss is wanting in Cornwall, and properly speaking mica-schist only shews itself in the southern parts of the peninsula, while the killas rests directly upon granite of one kind or the other. The mine-granite corresponds with the "granite and gneiss" formation of the central plateau.

To shew that this comparison is just it will suffice to specify the conditions of these rocks. The mine-granite resembles a metamorphic rock, being divided into beds. This very interesting character of *bedding* seems to be pretty general in the county, and it has not escaped the attention of geologists.[§] It is very evident in the quarries, and the workmen profit by a knowledge of it. Thus, at the quarries of Carnsew (Penryn) and of Polcanago (Stithians), opened in the mass of Carn-Menelez, they often make great blasts in an almost horizontal direction, where the beds are well-defined. At the Cheesewring, towards the north of the Caradon district, the quarries are opened with reference to the direction of these beds or sheets of granite. "The beds or sheets of granite " says Mr. Henwood,* " which, differing much in thickness and declining 5°—10° towards all sides of the hill—conform in some measure to its contour." A little further on, speaking of the cupriferous deposits of the same district, he adds that the lodes underlie *towards* the granite, i.e., contrary to the bedding of the granite or schist.

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[*] Remarks, p. 4.

[†] Ibid. "In this primitive granite no mine of any kind yielding a profit has hitherto been discovered."

[‡] Explication de la Carte Géologique de la France, Vol. 1, Chap. II, p. 109-118.

[§] Henwood: Address, p. 10, "a bedding approximating in various places to the contour of the surface often gives the rock a somewhat gneissose character.

Mine-granite is naturally unfit to furnish fine blocks of ashlar, so that it is better known by its effects upon the veins passing into it than by any openings made upon it from the surface. The inclination is variable, but it corresponds pretty accurately with the line of junction of the killas and granite,† which "makes with the horizon an angle of 20° to 45°."

The stratification of the killas is often indistinct in the metalliferous regions, and especially in the immediate vicinity of the lodes, on account of the abundance of joints, but the planes of slaty cleavage seem to coincide pretty well with the true bedding of the strata. "The alterations in the characters of the slate rocks appear to take place at right angles to the strike of their cleavage, and hence the succession of their laminæ must indicate if anything can do so the successive periods of their deposit."‡

The killas varies much in different districts. Mr. Charles Thomas§ warns us against certain schists which, if not completely sterile, are unproductive of metallic minerals, and which occupy zones of considerable extent in the two counties. As extreme types he indicates on one side the roofing slates, on the other true mud-stones.

In each mining district we may observe a series of beds, often distinguished by their color, which present, like the beds of mine-granite, hardness of several distinct degrees. The hardest are the hornblende schists, sometimes passing into true greenstone ("ironstone" or "irestone" of the tin and copper mines) which either constitute a series of intrusive beds, as in the extreme west of the peninsula, or else are intercalated with the killas, like the dioritic bands to the north of Camborne.

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* Met. Dep. 1871, part 1. p, 672, 674-675.

† Henwood : Address, p. 2.

‡ Ibid : Met. Dep., 1843, pp. 158-152.

§ Remarks, p. 21 and p. 4.

Generally, the schistose strata are tolerably thick, and less inclined than the surface of the granite which supports them. Their strike proceeds in a great curve upon the flanks of the granite masses. They are, indeed, in some places subject to minor plications, but in a much less degree than the carboniferous schists of Devon, which have been under the influence of the upheaval of the great mass of Dartmoor. Compared with the ancient schists of many other countries, the killas of Cornwall, in spite of numerous variations of direction and inclination, is very little disturbed.

Sir H. de la Beche has endeavoured to follow up and to connect, step by step, the beds observed in different districts. The sheets of the Ordnance Map (on a scale of 1 inch to the mile) contain many arrows indicating the dip of the beds. Mr. N. Whitley* has continued this delicate but most important study, and in a picturesque form has condensed upon a map, on the scale of 1 inch to 3 miles, the results of his observations made from 1853 to 1858. This map shews clearly the schistose strata forming a mantle around the granite masses. The map also indicates two exceptional facts—*horizontality* of the strata for a small distance to the west of Liskeard and the south of Padstow—and *verticality* near Saltash.

The mines of Cornwall and Devon are variously grouped in districts by different authors. Such a classification should not be arbitrarily devised, because it presumes that the mines of each group have characters in common.

Mr. Robert Hunt has adopted for his "Mineral Statistics of the United Kingdom" a very simple classification. Cornwall is divided into four great districts, the west, west-central, east-central, and east, while the whole of Devon forms one single district. The same classification includes both tin and copper mines (as well, also as those of iron, lead, &c.), many of which are indeed the same. His west-central district contains nearly one half of the mines, and its annual production of tin and copper exceeds in value that of all the other districts put together, Each of Mr. Hunt's groups is connected with one of the great granite masses, i.e., proceeding from West to East—Penwith. Carn Menelez, Saint Austell, Bodmin, and Dartmoor. The granite foundation of the county is also exposed to view at other points forming islets (or outliers) of minor importance. These are Tregoning and Godolphin Hills, which are situated between the granite masses of Penwith and Carn Menelez, but not related to them, the granitic cape of Cligga Head upon the north coast, which plays a more important part than its extent would seem to indicate; finally, the islets of Kit-Hill and Gunnislake, the connecting links between Bodmin Moor and Dartmoor, form of themselves the axis of a district.

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* I owe to Mr. Whitley a very excellent manuscript copy of his map of the strike of the slate beds in Cornwall and Devon; his memoir is mentioned in the annual report of the Royal Geological Society of Cornwall, published in 1865.

Mr. Henwood has described twelve districts—ten in 1843 and two others in 1871.

Mr. H. C. Salmon* in enumerating twenty, gives four for Devon alone.

In the following table I have brought together the divisions of Mr. Robert Hunt and Mr. Henwood, and I have added in the intermediate columns the names of the masses and islets of granite.

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* Mining and Smelting Magazine, Vol. V, 1864, pp. 258 and 328.

TABLE I.

County.	Mining Districts for Tin and Copper.		Masses of Granite.		Principal Tin and Copper Districts.
			Large masses.	Small masses and outlyers.	
Cornwall.	West	West of Truro.	Penwith	....	St. Just
				....	St. Ives
				Saint Michael's Mount	
	West Central		Carn Menelez	....	Marazion
					Gwinear and Crowan
				Tregoning and Godolphin hills	
				....	Helston
				Carn Brea	Camborne and Illogan
				Carn Marth	Redruth and Gwennap
				Cligga Head	St. Agnes
	East Central	From Truro to the Tamar.	St. Austell ...	Castle-an-Dinas	
				....	St. Austell
				Belovely Beacon	
	East		Bodmin	....	Caradon
				Kit Hill	Callington and Calstock
				Gunnislake	
Devonshire			Dartmoor ..	....	Tavistock, etc.

The following are the principal east and west Systems of upheaval, which have elevated the ancient rocks of Cornwall, and to which the fissures of the tin and copper lodes are due. Up to and including the Permian Epoch there are six East and West Systems:—

Finistère	E. 21° 46′ N.
Morbihan	W. 36° 13′ N.
Westmoreland	E. 40° 24′ N.
Land's End	E. 8° 23′ N.
Ballons	W. 5° 0′ N.
Pays Bas	E. 14° 55′ N.

Four of these bear north of east; two only, those of Morbihan and Ballons, north of west. Within half a degree their directions are,—

Finistère	22°	N. of E.	Morbihan	36°	N. of W.
Westmoreland	40°		Ballons	5°	
Land's End	8°				
Pays Bas	15°				

The first group is the best developed, and corresponds with the directions of the principal lodes in almost all the districts. This is shewn by bringing together the preceding figures and those given by Mr. Henwood, as in the following table :—

TABLE II.

Great Divisions		Districts.	General bearing of the Lodes according to Mr. Henwood.
Cornwall.	West	St. Just	Between N W. and N. (av. W .35° N)
		St. Ives	Mostly N. and E.
		Marazion	The principal lodes bear E. 20°N.
	West Central	Gwinear and Crowan	Many E, 25° N. some W. 20° N.
		Helston	From E. 15 to 35° N.
		Camborne	From E. 20 to 40° N. Some diagonal lodes or "caunters" W. 10 to 30° N.
		Redruth	From E. 15 to 30° N.
	East Central	St. Austell	E, a few degrees N., and others towards N.W.
	East	Caradon	Average E. 18° N. included, between E. 35° N. and W. 5° N.
Devonshire		Tavistock	Average E. 9° N. *i.e* nearly E. and W.

Of 292 lodes registered by Mr. Henwood,* the angle of 40° contained between E.W. and E. 40° N. includes 177, *i.e* 60 p.c. are contained in a range of 22 per cent. of the circle.

The E.N.E. direction which generally prevails for the lodes is also that of the great metalliferous zone distinguished by Capt. Chas. Thomas, who remarked that the profitable mines were all included in a zone about twelve miles wide, extending from the Land's End to Exeter, a distance of about 108 miles, in an E.W. (mag.) direction.†

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* Met. Dep. 1843, Table CIII.

† Remarks, p. 18.

If we draw from Cape Cornwall a line bearing E. 21° 46′ N. parallel to the system of Finistère it will traverse the mass of Penwith at the following points, viz., Carn-Kenidjack (640 feet high), Ding Dong tin mine, near the south foot of Trink Hill (652 ft.) It then crosses the Hayle estuary, grazes the north side of the outlier of Carn Marth, passes through Carclaze near St. Austell, crosses the Tamar at Calstock, and thence in the same direction after crossing Dartmoor arrives near Topsham, at the head of the great estuary of the Exe. This line cuts through the masses of Penwith and Dartmoor, leaves that of Carn Menelez to the right, those of St. Austell and Bodmin to the left, and finally, being prolonged to the W.S.W. it grazes on the north the Scilly Isles.

It represents pretty well upon this length of about 140 miles the fundamental axis of the peninsula But in consequence of the geological antiquity of the phenomena the direct influence of the System appears only to a limited extent, which, however, shews itself clearly in the west-central district.

The three masses of Carn-Menelez, St. Austell, and Bodmin form the landmarks of the principal chain of Cornwall. A line bearing E. 40° 24′ N. parallel to the system of Westmoreland joins the granitic islet of Carn Brea (740 ft. high) with the high peak called Brown Willy (1368 ft.) in Bodmin Moor. This is marked even now by the relief of the ground, and by numerous lodes of which some, near Camborne, contain tin and copper; others in the neighbourhood of Chiverton and Newlyn contain argentiferous galena in killas.

From Carn Brea the line passes to Trefula in the islet of Carn Marth; touches the killas from Jenkin's Barrow (457 ft.) near Mitchell, to Carvinack near St. Enoder, and to Indian Queens, and is continued between the outliers of Castle-an-dinas (729 ft), and Belovely Beacon (765 ft.); entering Bodmin Moor a little north of Blisland, and by Carbilla Tor (860 ft.) and Garrah (1060 ft.), reaches Brown Willy, and leaves the mass at West-Carn to the east of Bray Down. There are other lines parallel to this which are pretty evident, such as that from Wendron (400 ft.) in the Carn-Menelez mass, by Watch Hill (850ft.), and Helmen Tor (687 ft.) in the St. Austell mass; near Brown Gilly (1100), Trewartha (1050ft.), and Hawks Tor in the Bodmin mass. There is also that which follows part of the North Coast through St. Agnes Beacon (621 ft.), and another line which passing through Pendennis Castle in Falmouth Harbour cuts the point of the Black Head in Tywardreath Bay.

Subsequently, the System of the Land's End has upheaved the Devonian formation. It is interesting to follow a parallel of this System bearing E. 8° 23′ N. through the summit of the outlier of Kit Hill, (1067 ft.) Eastwards this line traverses Hingston Downs and the outlier of Gunnislake, following its greater axis; enters Dartmoor at Putor, passes through North Hessary Tor (1730 ft.) near Princetown, towards Rippon Tor (1549 ft.). Westward it cuts successively Caradon Hill, Cardinham-Bury (840 ft.), and the granitic point of Warleggan at the S.W. extremity of Bodmin Moor; and follows almost exactly the anticlinal axis of St. Breock Downs (Great Stone 739 ft.). If through St. Agnes Beacon we draw a second parallel, it passes about a mile to the southward the range of killas hills of Perranzabuloe and Jenkin's-barrow, passes the foot of St. Mewan Beacon near St. Austell and on to the Par Consols Mines, thence to St. Veep, to St. Germans, by the trap rocks of Saltash, and finally makes its exit at Hope's Nose near Torquay.

These lines parallel to the systems of Finistère, Westmoreland, and Land's End, are but a small proportion of those which may be profitably followed on the Maps of the Geological Survey,* but they will doubtless suffice to indicate the intimate relations which we may recognize between the E.N.E. directions of the rocks and those of the principal lodes in most of the districts.

As to the directions of Morbihan and Ballons, the latter is clearly marked in the east-central, and some of the mines of the eastern districts. The combined effect of the two systems is found in the caunter lodes of the west-central district, and finally, the direction of Morbihan may be observed at the western extremity in the lodes of the St. Just district, where it predominates. It also occurs in a certain number of veins in the St. Austell district.

This is not the place to enter upon the study of each of these districts, but we may remark that the most important lodes are situated upon the north or south flanks of the granite masses. For instance, to the westward,—St. Ives on the north flank of Penwith; Camborne and Illogan on the north flank of Carn Brea; a great part of Redruth and Gwennap on the north and south flanks of Carn Marth; St. Agnes to the south of Cligga Head; Crinnis, Charlestown, Pembroke and Polgooth Mines on the S.S.W., and Par and Fowey Consols on the S.S.E. of the St. Austell granite; Caradon Mines on the south of Bodmin Moor; Callington on the south of Kit Hill and Gunnislake; and finally upon the north of Gunnislake the rich mines of Devon Great Consols near Tavistock.

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* It is of course necessary to take into account the convergence of meridian northward.

Other districts or parts of districts are, on the contrary, situated on the east or west flanks of the masses, and many are contained in the intermediary basins of killas. Thus, St. Just is upon the west flank of the Penwith granite, and the direction of the lodes there differs much from that of the contact of the granite and schist. Marazion is on the eastern side of the same mass, on the north of St. Michael's Mount, and the west of Godolphin and Tregoning Hills. Crowan is clearly subordinate to the western side of Carn-Menelez while Gwinear, is related to both Carn Menelez and Godolphin Hill. The rich tin mines of Wheal Vor and Wheal Metal in the Helston District are equally between these two masses. Upon the east flank of Carn-Menelez is the old and celebrated Tresavean Mine, and passing over a great space we find Wheal Friendship upon the western flank of Dartmoor. Finally, some mines occur entirely surrounded with granite, of which the little Wendron district is an example.

The lead lodes of Cornwall have entirely different bearings. I have already mentioned the existence of the E.N.E. lodes in the Newlyn and Chiverton districts; other lodes of the E.W. group are known at Budnick, nearer to St. Agnes, and at Swanpool, near Falmouth. Nevertheless, the north and south lodes, or true metalliferous Cross-courses are most important, from those of the neighbourhood of Exmouth, those of Beeralston and Beerferrers on the river Tamar, and others to the south of Liskeard in East Cornwall; to the lodes of Garras, northward from Truro, of East Wheal Rose, Wheal Golden, and others near Perran-Zabuloe. Still further westward lead-bearing cross-courses are known, but they are unproductive, except those at Wheal Rose and Wheal Penrose, near Helston.

Summarising the general characters which are developed in the preceding pages we may say—

The rocks of Cornwall in the neighbourhood of the mines are composed of masses of granite and beds of killas, tolerably thick and relatively regular. As we have stated, the favourable strata are ordinarily of moderate hardness, whilst generally the unfavorable strata are excessively hard. Frequently, in fact, those bad parts which are too tender belong to some good stratum which, over a certain extent, loses its *moderate* hardness and becomes rotten; at any rate most districts contain these over-tender beds.*

The required alternation of strata of unequal resistance corresponds with the occurrence of a *non-homogeneous rock*. In a homogeneous formation composed of precisely similar strata, beyond the mere separation of the strata we cannot imagine a fracture fit to engender subterranean channels, for a *plane* fissure will be the necessary consequence of its homogeneity. Therefore, although there may have been relative movement, the two walls of the opening will not cease to be in contact over their whole extent.

The want of homogeneity alone permits of an irregularity of fracture. In Cornwall the alternation of strata, almost homogeneous individually, but dissimilar as compared with each other, determines the furrowed fissure which most often manifests itself by simultaneous variations of dip and direction in the lode.

The principal east and west lodes have a mean dip of about 70°, whilst the inclination of the rocks is often 15°, 20°, or 30°, and rarely more than 40° or 50°. It is therefore very clear that P is greater than i.

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* With these views we may thus interpret the diagrams 6 and 7, plate III. Leaving the good beds b_1, b_2 and the mean dip P unaltered, but substituting beds which are too hard for the too tender beds. Let us suppose that the fractures *Fc* and *Fa* result from a sinking of the hanging wall. The good beds would be broken almost as shewn, but the bad ones would yield themselves (*Fc* or *Fa*) to inclined fissures, which make up for the steepness of the good ones so as to compose the mean dip. These fissures then become planes of sliding. As to the lodes *Fc* it may be noted that if the inclination of the normal plane is a sort of limit of the dip of the fracture in the too hard beds, nothing analagous exists in the too tender beds. The fissure may therefore dip less than the normal plane.

The phenomena of walls resulting from the separation of strata (entre-baillement) so characteristic of certain deposits in other mining countries, are scarcely of interest in Cornwall, except at the points of contact of dissimilar rocks such as killas and granite or killas and elvan. Finally, the value of *a*, the angle comprised between the strike of the "country" and the bearing of the System of Fracture is often very small.

The E.N.E. lodes for example, upon the N. and S. flanks of the masses present channels but little inclined to the horizon. The dip of these channels increases with *i*, and within certain limits with *a*, so that in a given rock, the bearing of the lodes of which diverge sensibly from that of the strata, until the angle *a* equals 30°, 40°, or 50°, the normal rich parts or *shoots* are so much more inclined. This is observed upon the E. and W. flanks of certain masses, or in the secondary lodes of other districts.

To these general statements we must add that the dykes of elvan have upon many points a very notable influence. They cut through granite and schist; being met with in a district entirely composed of killas they indicate the probable presence of granite at a moderate depth, at least we may presume its existence in the depths of the lodes of tin and copper, which in Cornwall connect themselves with the granite rocks. They are generally large, their bearing is tolerably analagous to that of the principal lodes in each district. They dip more than the rocks and less than the lodes. In qualifying as accessory the riches which attach themselves to them, our object has been to differentiate them from the normal rich parts. The elvans, it is true, form for the lodes a kind of encasing rock or "country," but even from a mechanical point of view their influence is so complex as to become an object for particular study.

c. Comparative statements as to the Lead district of Alston Moor in Cumberland.

Mr. W. Wallace in 1861 published* a very interesting work upon the lead mines of Alston Moor. The descriptive part of this work includes a map of the district and a series of very instructive sections. If it is impossible for us to accept the theoretical views of the author upon the mode of filling of the veins;

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* The Laws which regulate the deposition of Lead ore in veins, by W. Wallace.

still we cannot too much praise his attentive study of the conditions necessary to form and to maintain the subterranean channels of the lodes.

The following is a short extract from Mr. Wallace's book:—

"The carboniferous series at Alston-Moor is essentially composed of alternate beds of quartzose sandstone, argillaceous schist and limestone. The *great limestone* has a thickness of 63 feet; deeper down is found the Scar Limestone of more than double that thickness, but hereabout it is less explored than the preceding. The beds are only inclined a few degrees; in this respect they contrast with the schists of Cornwall, and we may say that they constitute a horizontal formation.

"There are three groups of veins.

"1. The E W. veins, of which the directions are often inflected, and turn to N. of E. in going eastward. Their bearings are comprised within a *useful angle* of 60°, of which the limits are E. 52° N. and E. 8° S.*

"2. The cross-courses are generally straighter and less divergent from their direction, which is N. 22° W.

"3. The quarter-point or diagonal veins form two sub-groups, one bearing about N. 13° E., the other W. 33° N."

In connection with these different veins "flats" or lateral deposits occur, specially limited to certain beds.

The quarter-point veins are in general very small, and their useful effect is concentrated at their junctions with the lodes properly so called, which they very much enrich at these points.

It is the resisting beds, the limestones especially and sometimes even the sandstones which enclose the riches of the E.W. lodes. As to the cross-courses they only contain mineral while between walls of tolerably thick beds of limestone.

The argillaceous schists are sterile, besides which the enormous quantity of clay resulting from their crushing has often obstructed the subterranean channels and so played a considerable part in the separation of the rich parts one from another. The good beds here are the hard ones, they have been broken in planes of least resistance i.e. at right angles to the bedding, and almost vertically; the schistose beds have furnished

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*** The magnetic bearings of the author are here converted into true bearings, taking for the date and country under consideration a west declination of 22°.**

by the inclination of the fissure a component which is oblique to the mean dip. Fig. 5,* pl. I is a section of a rich east and west vein in Alston-Moor.

The schistose pillars offer very little resistance to crushing, but lend themselves readily to a sliding of the hanging wall. Owing to the marked character of the beds upon each side we are able to measure accurately the amount of the downfall, not only for each vein but in different parts of the same vein. Hence it follows that the size of the rich parts, or the separation of the vertical walls is in direct relation with the height from which the hanging wall has slipped over the foot-wall, while the fall has not exceeded certain practical limits. In fact, in order that the subterranean channel may be maintained, both sides of it must be hard rock, so that the descent of the hanging wall must not be such as to bring the argillaceous zone of the hanging wall opposite to the hard and vertical face of the foot-wall.

The amount of faulting in the quarter-point veins is very small; variable but notable for most of the good E. W. veins (5,10,15, 18, 24, 36, and exceptionally 60 or 84 feet), variable also, but often greater for the N.S. cross-courses (18, 36, 40, 60, 84, 96, 120, 260 feet.)

The comparative poverty of the cross-courses is not unconnected with the greater extent of the faults in their case; where the beds are thin the projections of the little steps are masked, or even obliterated, while only the thick beds of limestone can furnish two solid walls; and the miner may think himself fortunate if the channel has not been entirely obstructed by the products of attrition. The unfavorable influence of great faults has been recognised in other carboniferous limestone districts. Mr. Lonsdale Bradley, in a work on the lodes of galena in Swaledale, Yorkshire (1862), remarked on this subject, "large throws occur in general in the cross-courses bearing N.S. or N.W., S.E., and the veins in which they occur are always unproductive, because the favorable rocks, chert or limestone, do not occur opposite to each other.

Constant study of stratigraphy alone can in similar mines furnish a scientific basis for the labors of the engineer. Excluding the particular case of *flats* all the riches appertain to the class which we have called normal rich parts in Cornwall.

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* W. Wallace, fig. 2, pl. x, p. 116,

The object of the miner in this district is to ascertain the causes of variation in the quantity and value of the plombiferous filling, and those circumstances which assure its continuity in the assigned zones. He is guided by the distinctive characters of the strata, their small slope corresponding to the almost horizontal shoots, so that he has not, as in Cornwall, to concern himself with frequent turns in the level. On the other hand, a knowledge of the Stratigraphic Systems will enable the miner to utilize the identity of their directions with those of the larger elements of the inflected veins; it will assist him to establish more exactly the chronological order of the fissures and their re-openings, and to arrive still further towards an appreciation of the mechanical phenomena which have governed the formation of the subterranean channels.

d. Characteristics of the Lead district of Cardiganshire.

I have already cited (pp. 18, 22,) the paper contributed by Mr. Warington W. Smyth to the Memoirs of the Geological Survey in 1848. I follow him almost exclusively in summarizing here the essential characters of the rocks and the rich parts of the lodes.

The metalliferous zone extends from N.N.E. to S.S.W., with a length of about 40 miles and a breadth from 5 to 22 miles. The rocks comprise a series of beds which vary from soft shale to coarse sandstone and conglomerate, and include a great number of fissile schists, flagstones, and argillaceous rocks.

They belong to the Lower Silurian formation, and form part of that vast territory which, in the counties of Carmarthen, Cardigan, Radnor, and Montgomery, seem to contain nothing more ancient than the Caradoc and Bala beds, nor more recent than the base of the Llandovery rocks.* The elevation of the ground is due to the repeated convolutions of the same strata, the entire district is merely a series of great undulations of which the axes are directed N by E.

The mines form six natural groups or productive zones parallel, to the axes of these undulations.

1*st*. Commencing at the westward, with the sterile sandstones of Aberystwith, the lodes of the first group are small and yield galena which is poor in silver, a little blende, and, at two or three points, some copper pyrites. The beds are moderately inclined to the west, but pass constantly into roofing slate, which is unfavorable to the continuity of the rich parts.

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* Murchison—Siluria and Silurian System, 3rd Edition 1859, p. 81.

2nd. The second group received two centuries ago its name of the *Welsh Potosi.* The schist is of a lighter color tending to a bluish or greenish grey with a sort of greasy lustre, but it contains some beds of a more massive character. In consequence of this it would seem that the size of the lodes is increased to 20 feet or more. The principal lodes are worked at Goginan Cwm Sebon, Cwm Sylog, Daren, Pen-y-Cefn, and Esgair Hir. The proportion of silver sometimes amounts to 38 ounces per ton of lead.

3rd. In the third group the characters of the country and of the lodes are all subject to great variations. Sandstones and roofing-slates are met with as well as the grey indurated argillaceous rock which encloses the lodes. At Llwyn Malys the galena is pretty rich in silver; at Frongoch, it is accompanied by blende. The Estymteon lode contains some veins of iron pyrites, that of Pen Drosgol some oxide of manganese.

4th. This group consists of lodes of galena, containing but little silver, with blende and carbonate of lime at Logaulas, Esgair y Mwyn and Nant y Creiay; at Llanfair Clydogau, and at Glogfach (1860) the lead ore contains silver. To the north of Plymlumon Fawr, where sandstones and fissile schists abound, they have not discovered up to this time any trace of mineral.

5th. In this group the principal mines are Cwm Ystwith and Deliffe. In the south frequent intercalations of arenaceous matter are observed, but to the north of Deliffe argillaceous schists; numerous lodes of copper have been worked in this group.

6th. This metalliferous band is limited to the east and north by the sandstones which crop out from under the Wenlock shale. Some of the mines are characterised by the presence of witherite and barytes as a gangue with galena.

The predominant direction of the lodes is E.N.E., which is within a few degrees that of the most productive deposits Goginan, Daren, Glogfach and Cwm Ystwith; at Old Logylas and Esgair y Mwyn they reach 40° and 44° N of E.; at Frongoch and Grogwynion they fall to E 9° to 12° N, etc. Many of the lodes in passing to the east of the river Rheidol are inflected strongly towards the north. Upon the borders of the mineral district some lodes of galena of little importance are known, which approach a meridional direction; and finally, the lode of the Tre Taliessin may be mentioned as an exception (N.W.), which was very productive; and also the Comet Lode (W.N.W.) which was rich at its junction with the principal lode of Cwm Ystwith. The general underlie of the lodes varies from 60° to 80°.

The class of cross-courses is represented by some small transverse fissures; sometimes they are "slides" full of clay; sometimes simple *partings* of the rock. The result is often a *heave* of some feet.

To return to the metalliferous lodes and the condition and characters of their rich parts.

The direction of the lodes as we have said in the first chapter is subject to repeated variations within short distances. Compared to the bends and zigzags of the levels, the changes in the underlie of the lodes are less marked; and when the lode becomes flatter the resulting impoverishment is less evident than in other mining districts.*

Some veins have a "banded" or "combed" filling, but the brecciated structure prevails, angular fragments of schist of all sizes abounding; the principal earthy gangue is quartz, while fluor spar is absolutely wanting. The ore-bearing portions or rich parts have suggested many of the remarks made elsewhere. Thus the junctions of the lodes with each other, or of lodes with their branches are favorable, especially if the veins make an acute angle. At Logylas and Glogfach again the branches play a great part; at Goginan and elsewhere it is the coming together of many veins in one which constitutes the rich parts.

When two lodes cross each other at a considerable angle the riches may continue in each near the intersection, but they disappear at a little distance if the country is of an unfavorable nature.

The accessory rich parts form almost exclusively *shoots of ore;* it is the same with the normal riches, which are subordinate to the encasing rocks and dip with them. The influence of the country is clearly defined by Mr. Smyth, who concludes by saying, "The actual following of the vein in a level certainly proves to be an index to the rock which it traverses, for, as soon as it diminishes in size, and is filled with soft argillaceous matter, the adjacent rock is invariably found to have degenerated to a shaly character. In Cwm Sylog, some bands of fissile slate, which at the surface resist decomposition and degradation better than the more massive beds, are traversed by the lode, and exhibit this result very distinctly; in the more productive parts of the mine, the rock, as in all the Goginan district, is so solid that its bedding would often be indistinguishable but for the stripes of a darker color which here and there relieve its pale grey tint; but where the lode passes into the "cross-measures," as they are termed, of slate, not a vestige of ore remains to tempt the miner onwards.*

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* P. 659.

The preceding quotations will suffice to shew the existence of well-marked analogies and contrasts between the phenomena *(allures)* of the lodes of Cardiganshire, and those of the principal lodes of Cornwall.

In both countries an E.N.E. direction predominates, but the strike of the schists of Wales (N.N.E. and N ¼ E) only occurs exceptionally in Cornwall.

The differential character as to the form of the deposits of the two countries appears to be connected with the value of a.

Viewed generally we have seen that the stratification of the Silurian schists of Cardiganshire is determined by the great undulations which have been recognised, but different upheavals have somewhat modified this general strike of the rocks; thus, from Aberystwith to Logylas the N.N.E. direction (Longmynd) seems to prevail.

If we compare the mean direction of the lodes (E.N.E.) with that of the schists (N.N.E., and N ¼ E) the angles comprised (a) are from 45° to 56°. With these same rocks the six east and west systems already considered in Cornwall would form considerable angles.

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* **Memoirs of the Geol. Survey, Vol. II, part II, p. 667.**

TABLE III.

East and West Systems.		Approximate values of α.	
		The Strike of rocks being N ¼ E.	NNE.
North of East	Finistère	58°	46°
	Westmoreland	40	27
	Land's End	71	60
	Pays-Bas	65	54
North of West	Morbihan	63	74
	Ballons	85	74

The Westmoreland system gives a considerable angle, but less than 40°; those of Ballons, Morbihan, and even the Land's End cross the strike of the rocks with angles from 60° to 85°; the Finistère system cuts the strata at an angle approaching 45°. The inclination (i) of these latter is often pretty great, but always very variable; one of the general sections of the Geological Survey taken almost at right angles to the strike of the beds, shews these variations; but the N.N.E. lodes cut through the undulations and plications obliquely. The more complex fractures which result from these natural conditions produce irregular flutings (*cannelures*) inclined to the horizon and related to the variations rather in direction than in dip.

III. *East and West Lodes of Cornwall.*

a. Formation and opening of the fissure by the descent of the hanging wall.

The opening of the subteranean channels has been caused by the descent of the hanging wall, and the inclined faces of the flutings have served as surfaces of motion, and afterwards as pillars during the periods of relative stability; the faces most nearly vertical have formed the walls of the principal conduits, and whatever the physical and chemical modifications of these walls may have been subsequently, their separation has always had an influence upon the size of the rich parts, often even it has been the determining cause.

When a section of a lode is made by a vertical plane (π) perpendicular to its mean direction, the profile of the vein oscillates round the straight line which corresponds with the greatest inclination of the mean plane of the lode; this straight line gives with the horizontal the mean dip (P) (fig. 2, pl. 1); some of these elements (the components of which are almost rectilinear) are steep, others flatter, and they form by their intersections with the plane π two series of flutings. Whenever a has any magnitude the edges of the flutings are oblique to the horizon, they are not then perpendicular to the plane π; and the elements of the sinuous profile do not then agree exactly with the dip of the corresponding parts of the lode: thus in the workings, a winze or inclined shaft sunk parallel to the trace of the plane π, in descending upon the footwall of the lode could only preserve its own footwall, or *sole* normal to the plane π, by cutting into the footwall sometimes a little to the left, sometimes a little to the right. However, these angular differences are here practically neglected, and the angles Pr and Pm measured upon the profile may be employed as values sufficiently approaching the dip of the rich parts (Pr) and the poor parts (Pm).

Considering the diagram fig. 1, pl. IV, as a cross-section of a lode, X Y is the horizontal, X A C D the hanging wall, X A B the footwall; the part X A is the surface of motion; A B and C D are the good walls of which we are studying the separation B C. I make $AXY = ZCY' = Pm$; $DCY' = Pr$; $BC = \epsilon$; $AB = H$. I have in the rectangular triangle A B C the acute angle $BAC = (Pr - Pm)$; of which I take to express the opening ϵ of the walls.

$$\epsilon = H \text{ tang } (Pr - Pm) \qquad (1)$$

Now H is not the greatest vertical elevation from which the hanging wall has descended, although the difference is very little. I take the horizontal B B′ and let fall the perpendicular A B′; then in the rectangular triangle A B′B the angle $BAB' = \cot Pr$; the true height of the fall h is then

$$h = H \sin Pr$$

and the formula becomes

$$\epsilon = \frac{h \text{ tang } (Pr - Pm)}{\sin Pr} \qquad (2)$$

In consequence of the underlie of the rich parts the formula (2) may frequently be simplified. The value of Pr is generally more than 70°, so that the sin of Pr becomes very nearly unity. By suppressing the $\sin Pr$ in the denominator the formula (2) would give within two, or three, five-hundredths the value of ϵ which would follow from substituting h for H in (1). Finally, when $Pr=90^\circ$ (fig. 2, pl. IV) we have $H=h:(Pr-Pm)=\text{cotan}\,Pm$; of which

$$\epsilon=h \cot Pm \qquad (3)$$

This latter formula suffices almost always for Alston Moor; where well-defined strata allow of accurate measurement of the downfall h, and Pm can be determined from the plan of the mine it would certainly be interesting for the study of corrosions to compare the calculated opening ϵ with the size observed. In Cornwall the indefiniteness of ϵ results from the almost impossibility of estimating the value of h; the descent of the hanging wall may sometimes be ascertained when the lode cuts across the junction of two different kinds of "country," but those points where the descent is visible are seldom suitable for measurement, because such junctions are usually accompanied by local disturbance.

As a compensation, the numerical conditions abound as to the underlies Pr and Pm; and again, the size of the normal rich parts becomes nearly the value of ϵ, so that in utilizing the relative observations of size and dip we shall endeavour to connect them by the preceding formulæ, and to arrive, by an hypothesis, at the amount of descent which is most probable.

b. Size of the Lodes.

Every lode, says Mr. Henwood,[*] has in general one characteristic size, and Mr. Chas. Thomas[†] recommended the miners to prefer a lode of moderate ("good," or "fair") size.

This medium size of a given lode can only be determined by practical observation upon itself. From very many observations Mr. Henwood[‡] states that the average size of lodes containing,—

Tin and copper is	4 feet	7 inches
Those of tin alone	3 ,,	0 ,,
Those of copper alone	2 ,,	9 ,,

but he cites some examples which greatly differ from these averages.

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[*] Met. Dep., 1843, p. 241.

[†] Remarks, p. 5, 6.

[‡] Address, Rep. Miners' Assoc., 1872, p. 5.

TABLE IV.

Name of Mine.	Name of Lode.	Size.	
		Minimum.	Maximum.
Tincroft	Highburrow ...	3 feet 0 inches	48 feet 0 inches
Wheal Crofty ...	Engine	1 „ 6 „	20 „ 0 „
Wheal Vor ...	Main Lode... ...	3 „ 0 „	36 „ 0 „
Polladras Downs	Bor Lode	0 „ 1 „	4 „ 0 „
Polgooth	St. Martin's ...	6 „ 0 „	50 „ 0 „
Pembroke ...	....	A simple joint.	8 „ 0 „
Wh. Friendship	....	2 feet 0 inches	48 „ 0 „

But he adds, "these great variations, though sometimes sudden, are usually gradual; it is rare to find two parts of one lode differing greatly in size, which are separated by an interval of only a few feet, or even a few yards."

The great size of a lode results in general from a concord of favorable circumstances, for example :—

TABLE V.

Name and Situation of the Mine.		Size of the rich lode.	Nature of its contents	Country.	Date.
Devon Great Consols ... ... (*Tavistock District*)		20 33 feet 42	Copper	Killas	1858-66
Camborne and Illogan District.	West Wheal Seton	12 „		...	1858
	Dolcoath	20 „ 26 „	Tin	Granite	1858
	East Pool	21 „ 24 „			1866
West Chiverton ... ... (*Newlyn District*).		26	Lead	Killas	1866

At *Devon Great Consols*, in the part called Wheal Anna Maria, the country was a tolerably hard blue schist, in which the two principal north and south lodes formed a junction. The lode was composed of rich copper pyrites, with a gangue of quartz and fluor spar. Workings 20 feet in width were not rare, but a width of 33 to 42 feet was exceptional. In spite of the steepness of the walls and their comparative firmness, very strong timber, with occasionally a complete filling in of the cavity, was necessary.

At *West Wheal Seton* the rich zone of the south lode was at the 82 fathom level from 6 to 7 feet wide; at the 90, after a junction with a branch coming in on the hanging wall, there was 12 feet of very rich copper pyrites, with a gangue of quartz and a little carbonate of iron.

At *Dolcoath* the principal or "*Main Lode*," after its junction with *Harriett's Lode* afforded some magnificent workings. The walls were nearly vertical, composed of firm granite, and the lode contained tin in a quartzose gangue. Mr. Charles Thomas, the able manager of Dolcoath, who in 1858 kindly conducted me himself, took me into one of their great open workings which was from 20 to 26 feet wide and 60 feet high, an immense excavation, of which the walls sustained themselves without timber.

At *East Pool*, when the main lode reached the granite about the 135 fathom level, they discovered a large new lode, which a little deeper was found to contain large leaders of tin in a gangue of quartz, with much wolfram and copper pyrites. The main lode also became much larger in the granite. These somewhat abrupt enlargements were evidently associated with the change in the country.

At *West Chiverton* the principal lode (*Williams's*) bears 40° north of east; an important branch known as *Valpy's Lode* detaches itself from the hanging wall at a depth of 50 fathoms, and rejoins the main lode between the 90 and 100 fathom levels. Another lode (*Elizabeth's*) parallel to the preceding in direction, but having a greater underlie, formed a junction with the principal lode on its footwall, at about 80 fathoms depth. All these lodes underlie southward; Williams's is the largest, the galena there is disseminated through the gangue. In Valpy's lode it is more massive, and in Elizabeth's it is more argillaceous, and contains also more silver.

At the 90 fathom level the workings presented a very fine aspect. Stopes of 27 feet wide were being removed, the men standing upon the "deads." The back shewed a series of veins of galena, blende and quartz, and nearly every one was in places large enough to constitute a rich vein of twelve to sixteen inches in width. This great size and richness was evidently the consequence of the coming together of the three lodes.

This coming together of mineral veins to form junctions *(totalization)* explains how it is that the lodes of tin and copper have a mean size of 4 ft. 7 in., which is greater by about two feet than that of lodes containing only one of these metals. Without approaching here the interesting study of the relations of these metals in their deposits *(gîtes)*, we may note the existence of numerous cases of juxtaposition.* Very often the tin lode occupies the foot-wall, while the copper is towards the hanging wall, and a band of quartz and clay runs between the two. It is unnecessary to add, that whilst one metal forms a "strong vein" on one side, the other occurs also abundantly on the opposite side.

These examples of reopening, characterized by the deposition of different minerals, shew that the total size, other things being equal, results, not it is true, from the junctions of lodes of which the openings are distinct, but from the superposition in the same opening of two series of operations.

To resume our numerical statement, and taking for example one of the finest lodes of Cornwall, the main lode at Dolcoath, already mentioned.†

In January, 1873, they had commenced to drive the 314 fm. level, reckoning from the adit, at a total depth from surface of 342 fathoms; in length the lode is traced for 550 fathoms.

Whilst the other lodes in the mine bear 10° to 30° north of east (not reckoning the "Caunter Lode"), the *Main* Lode bears nearly north east and underlies to the south. Let us notice the modifications which it presents.

At the surface there was a very fine gozzan from 3 feet to 6 feet wide, which extended downwards to the adit level 28 fms. deep.

From the 10 fathoms level to the 160 it was very rich in copper ore, and had a width of from 8 feet to 16 ft.

The passage of the lode from the killas to the granite occurred between the 80 and 120 fathoms levels. Meanwhile the lode (F*c*), the slope of which was contrary to that of the country, and was to that depth comprised between 70° and 86$_o$ became more flat and thin. Its dip lessened successively to 68°, 57°, 50$_o$, and its size was reduced to 24 inches, and finally to 12 inches in the hard granite about the 170 fathom level.

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* R. W. Fox, *On Mineral Veins*, p. 90, 91.

† Henwood. *Met. Dep.*, 1843, Tab. 1. Mr. Josiah Thomas's "Description of the operations at Dolcoath Mine, with notes by Mr. Henwood. Rep. Royal Institution of Cornwall, 1870.

Between the 160 and 190 the copper diminished gradually, and tin was mixed intimately with it.

This poor zone discouraged the adventurers, and led to the abandonment of the works in depth. At length, through the energy of Capt. Charles Thomas, the sinking of the mine was resumed, and that which had been one of the richest copper mines became the most productive tin mine in Cornwall.*

From the 190 to the 220 fathom levels the size had been about 10 feet; below, as we have seen, it reached in places 20 to 27 ft.; the lode formed two large parallel veins, and at the present depth of 342 fathoms (1874)† it has a very fine appearance.‡

Let us suppose a model of these workings made to a scale of one thousandth the real size. A sheet of lead 3 feet 4 inches long, twenty-five inches wide, and in some parts from 1-30th to 1-10th of an inch thick, in others no more than 1-100th of an inch, but swelling occasionally to 2-10ths or 3-10ths of an inch, such will be the figure of one of the richest and largest lodes. On the same scale the mean width of the lodes of Cornwall would be represented by thicknesses of 1-20th, 1-25th, and 1-30th of an inch. Viewed in this manner, the vast subterranean channels richly filled by the metalliferous waters, which under the implements of the miner are transformed into caverns of imposing extent, only appear as thin veins in the ground. Nevertheless it is because these useful receptacles have been opened and remained so, that by a concourse of favorable circumstances,—quality of the walls, gradual movements, repetition of phenomena, and above all, form of the original fissure, and especially of the elements of its profile, the final result has been produced.

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* This success commenced a new era for the great mines of the Camborne, Illogan, and Redruth district, and has established for a part of Cornwall the fact of a possible occurrence of tin below copper.

† The mine has now, 1876, an actual depth of 354 fathoms from surface, and the lode is still very large and rich.

‡ Some figures of Capt. Josiah Thomas give an idea of the richness of Dolcoath. The sett is about 560 fathoms long and 140 fathoms wide. In 1870 the total production (of tin and copper) had reached the value of 5½ millions sterling, or for each yard on the length of the lode nearly £5,000.

c. Dips. P. Pr and Pm of a lode, and of its rich and poor parts; difference (Pr—Pm).

Mean dip P. Mr. Henwood estimates the mean dip of the lodes of Cornwall at 70°, that of the cross-courses at 80°.

In some parts of East Cornwall the lodes are less vertical, thus at Callington P becomes 50° or 60°, and a great many of the mines about St. Austell and St. Agnes are opened upon lodes whose dip is no more than 60o, and others are still further from the vertical. In general P is comprised between 65° and 75°; it is rarely less than 45° and rarely amounts to 90°.

We have said that the lodes F*c*, whose dip is opposite to that of the country, predominate; and shewn that the direction and angular value of the dip P are a probable consequence of the general phenomena of the fracture of the ground.

The essential character of the rich parts is their relative dip, it is expressed by making P*r* greater than P*m*; the angular difference (P*r*—P*m*) is not less useful to study than the absolute value of these two terms.

Difference (Pr—Pm). Every normal rich part is contained between two poor parts, which are less vertical, and of which the inclinations are sometimes equal, sometimes unequal. These circumstances have their influence through the descent of the hanging wall upon the form of the principal vein and even of its branches; they are probably due to the relative resistances of the beds to the rupturing force.

Strata which offer too great a resistance are in general unfavorable, because in the case of the lodes F*c* they are broken nearly at right angles to the stratification; it is well to observe how the dip (P*m*) and the bearing x of this plane varies in connection with the inclination (i) of the bed and with the angle (a) comprised between the strike of the rock and the direction of the system of fracture.

In Appendix B I treat the question from a geometric point of view, introducing in the formulæ obtained the numbers indicated by observation, and I then discuss the results of calculation.

Let us consider two adjacent beds; the lower of medium hardness, and therefore, by hypothesis, broken vertically, according to the direction of the System of Fracture; the upper bed is harder and is broken normally, the horizontal of the normal plane makes the angle (x) with the strike of the beds, and its line of greatest dip gives the angle (Pm) with the horizon. The two faces of the channel are then defined thus.

Faces.	Bearing.	Dip.
Flat part	x	Pm
Steep part	a	$Pr=90°$

The angular differences$=x-a$ and $90°-Pm$

giving the variations in longitudinal and cross sections.

The calculation shews that for each value of (i) the horizontal deviation is susceptible of a maximum. The System of Fracture corresponding to this maximum makes with the beds the angle (α') given by the formula, tang $\alpha'=\cos i$, and which, in consequence, has for its superior limit 45°, and decreases slowly as the inclination of the beds becomes greater.

As to Pm, if the System of Fracture is parallel to the beds ($x=0$) the dip of the normal plane is complementary to the inclination i of the rocks; but if the angle a is considerable, Pm increases at the same time; so that as a varies from 0° to 90°, Pm passes from ($90°-i$) to 90°.

In the following table, of which the particulars are taken from Tables 1 and 2 in Appendix B, I have brought together the inclinations i from 10° to 40°, the limits of a, comprising the group of principal lodes; the values of Pm corresponding to these limits o and a, and finally the complements of Pm.

TABLE VI.

Calculated values of Pm (in the case of a normal plane).

i Inclination of the country.	10°	20°	30°	40°
α. Varying from 0° to α'	0°—44°	0°—43°	0°—41°	0°—37°
Pm Varying from ($90°-i$) to	80 —83	70 —76	60 —69	50 —63
($Pr-Pm$), here$=$($90°-Pm$)	10 — 7	20 —14	30 —21	40 —27

These numbers are only exactly applicable in exceptional cases; in many of the lodes F*c*, however, the underlie of the normal rich parts approaches the vertical, so that Pr is comprised between 80° and 90°; the values of ($Pr-Pm$) are often but a few degrees less than the amounts of the fourth column. Let us suppose that the favorable strata maintain in several localities a moderate and almost identical hardness, whilst the bad beds are in some places very hard, in others, only a little less hard than the good, elsewhere again much more tender than these latter. Suppose, also, an equality in the thickness of the respective beds, their inclination i, the angle a and the mean dip P; the profiles of the lodes Fc would then have different sinuosities; in the first case Pm would be almost equal to the values given in Table VI; in the second greater; that is to say, the irregularities of the lodes become less as the difference between the resistance of the beds lessens; in the last case on the contrary Pm might be smaller, and the profile present inflexions of 30° to 40°; certain very "flat" lodes of the St. Agnes district furnish examples of this kind.

Supposing on the contrary all the particulars identical except the value of a, the irregularities become less in proportion as the *flutings* become more inclined, *i.e.* with the increasing values of a towards a' the lode cutting the strata obliquely, will have, with an equal mean slope P, a straighter profile than that of a lode which bears more nearly parallel with the strata.*

In his descriptive tables of the mines of Cornwall Mr. Henwood gives for each lode and each level the two extreme values of dip observed; so, also, as to the size of the lode, the two extreme limits; he then indicates the nature and the composition of the lode, and in a fifth column the nature of the encasing rock, with the direction and amount of its dip. The attentive study of these tables enables one to appreciate the connexion of these elements by their variations.

The lodes Fa exhibit flutings (*'cannelures'*) almost analagous to those of the lodes Fc, but some differences may be observed as to the values of Pm. Thus, a hard but fissile schist inclined 30° would be broken normally under a dip of about 60° or 65° for a lode Fc, whilst the mean slope Pm of the rough fracture (see fig. 8 pl. II) would only be 45° or 50° for the fissure Fa.

To sum up, the cross-sections of the principal lodes of both kinds (Fc and Fa) are subject to inflexions which are characterised by the following values of (Pr—Pm).

12° to 18°	very frequently observed.
6° to 12° and 18° to 24°..	less frequent.

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* This appears to be the case in most of the lodes of Cardiganshire.

24° to 30°	still less frequent.
30° to 40°	somewhat rare.
More than 40°	exceptional.

Recurring to the diagram, fig. 1, pl. IV, and admitting that during the descent of the hanging wall the edges of the beds remained in contact, and that the almost vertical walls of the rich channels were not subjected to alteration; let us consider the formula (2)

$$\epsilon = h \frac{\text{tang}\ (Pr - Pm)}{\sin Pr}$$

Neglecting in the denominator the difference between sin P*r* and unity, and making h=1 yard; the separation of the walls would be that of the tangent to the inflexion (P*r*—P*m*) of the profile. In the following table I have inserted the approximate values of ε, *i.e.* the tangents of (P*r*—P*m*) corresponding to the inflexions for each 5° between 10° and 55°. The third column contains the opposites of the preceding numbers—these are the amounts of fault necessary to produce a separation of one yard.

TABLE VII.

Inflexions of Cross-section.		Opening.	Fall.
Observations.	Pr—Pm	When h=1 yd.	When ε=1 yd.
Frequent	10°	0·176 yd.	5·671 yd.
Very Frequent	15	0·268	3·732
Frequent	20	0·364	2·747
,, ...	25	0·466	2·144
,, ...	30	0·577	1·732
Rare	35	0·700	1·428
	40	0·839	1.192
Exceptional	45	1·000	1·000
	50	1·192	0·839
	55	1·428	0·700

Calculating the amounts of fall which for inflexions of 15°, 20°, and even 25°, give values for ε analagous to the great openings mentioned in table V. we have

TABLE VIII.

Opening of good walls.	TOTAL FALL.		
	$(Pr—Pm)=15^{\circ}$	$(Pr—Pm)=20^{\circ}$	$(Pr—Pm)=25^{\circ}$
1·yd.	3 752 yds.	2·747 yds.	2·144 yds.
3·50	13·06	9 62	7·51
6·00	22·39	16·48	12·86
8·00	29·86	21·98	17·15
10·00	37·73	27·47	21·44
12 00	44·78	32·96	25 72

The great falls measured at Alston Moor upon the good east and west lodes, are from 30 ft. to 80 ft.; hardly differing from the figures of this table.

Similarly, for most of the lodes of Cornwall a fall of 2¾ to 3¾ yards would suffice for the separation of the walls of the principal channels to the extent of one yard.

Upon a model on a scale of $\frac{1}{1000}$ the movement would be from $\frac{8}{100}$ths to $\frac{16}{100}$ths of an inch, and if effected gradually it would be scarcely recognisable.

d. Condition of the walls of both channels and pillars during the descent of the hanging wall.

However small the amount of descent may be compared with the longitudinal extent of the lodes—the absolute movement of the hanging wall implies an enormous amount of mechanical force exerted very unequally upon the sides of the fissure. The rubbing of the faces in contact, results in a partial crushing of the rocks, *i.e.* prepares mechanically a fine material, which, acted upon by the water, becomes clay. Some lodes have their argillaceous selvages (*flucans*), which distinctly separate their filling from the enclosing rock. "Whenever the lodes coincide in direction with the joints of the rocks they appear to be bounded by smooth walls"* otherwise the sides being rough there is a gradual passage of lode material into the encasing rocks.

The sides are sometimes entirely obliterated—the walls of the cavity and its filling being completely amalgamated.

In Cornwall the "capels"† are the representatives of those siliceous selvages which by the metamorphism of the walls of the original fissure have, so to speak, welded the lode and enclosing rock together. This silicification may either accompany the deposition of mineral or precede it, at least, in part; in the latter case it may, sometimes, favorably modify the walls by strengthening them.

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* Henwood, address p 7 † Ibid. (See also R. W. Fox on Mineral Veins, p. 109.

As the surfaces of contact during the motion of the hanging wall are subject to a grinding force, some fragments will be detached from all such parts. The hanging wall—forming one side of a fissure out of perpendicular—has a constant tendency to fall by its own weight. At each new movement some secondary fissures will be produced, and these again will afford debris, which will mostly accumulate at the lower portions of the open spaces; but very often, also, portions will be detached and remain enclosed in the lode matter without appreciable fall, so producing a brecciated structure,* whilst elsewhere, being acted upon by water, these fragments may become globular, forming the nuclei of spheroidal concretionary masses.

This fracturing and alteration of the walls of the original fissure produces in many lodes a size very much greater than the opening (ϵ) already considered.†

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* Henwood. Address, p. 7.

† Mr. H. C. Salmon described a remarkable deposit of tin at Pednandrea Mine, near Redruth, in the Mining and Smelting Magazine in 1862, and made some interesting suggestions as to the effects produced by largely developed metamorphism in some stanniferous lodes. These phenomena are analagous to those which have elsewhere produced carbonas. He observes "The Engine Lode and Martin's Lode both underlie northward; the latter being much 'flatter' than the former, forms a junction with it on the foot wall about the 80 fathom level." .... "Between the 47 and the 55 the old men found a rich piece of ground west of the engine shaft; but it was below this, between the great cross-course and the vertical face of granite that the great deposit of tin was met with, extending downwards from a little below the 50 to the point of junction of the Engine and Martin's lode. The deposit made longest, largest and richest above the 68, from which level it was principally worked upwards.

For a length of 25 fathoms at the 68 the tin made in branches in the killas "country" by the side of the lode for 11 fathoms wide, the lode itself being only 4 feet wide. The richest part seems to have made about this level, to the south of the Engine lode between it and Martin's lode.

This great deposit which, in the old working was, I believe, named the great Carbona, is what the Germans would call a *Stockwerk*, a kind of formation for which it is rather odd we have no special name in our mining language. I consider this great deposit as eminently characteristic of a class of stanniferous formations common enough in Cornwall, but which are usually classed as "lodes."

I do not mean to say that they are improperly so classed, for I should consider that any metalliferous channel of ground with a definite direction and dip might properly be called a "lode," but the word has received a theoretical meaning implying, exclusively, a mineral deposit between the walls of an original fissure, which many of the richest stanniferous deposits in Cornwall called lodes certainly are not. Indeed, much of the misconception which prevails between geologists and miners on the phenomena of metalliferous veins is probably due to a misunderstanding as to facts and definitions. A miner speaks of a lode of such and

It is on the footwall of the original fissure that, in good strata, the modifications due to its reopening are least likely to have taken place. Consequently many of the best miners attach much importance to the appearance of this wall. They like what they call "a straight foot wall" or "a clean wall" as much as a footwall with good underlie. This is, in fact, the usual indication of a good initial fissure, which encourages the miner to hope for *one* large and regular vein, or, should this be wanting, for several veins or branches with irregular hanging walls.

If it is true that the hanging wall has been most generally fractured, still the foot wall has not always escaped the effects of the movements of the superincumbent masses.

Some secondary openings will have been produced from the first commencement of the descent of the hanging wall as well as at all other similar periods during the formation of the deposit; these appendages of the principal lode are the so-called lateral *branches.*

Of these the *feeders** are those which unite with the lode as they go deeper—the *droppers* are those which pass away downwards. The *joints* of the rocks often play the part of feeders or droppers.

The feeders are most favourable when the angles they form with the wall of the lode are most acute. Figures 2 to 5 plate III

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such a width with north and south walls, and the geologists at once declare that this whole width must have been originally an open fissure. This, the miner refuses to believe, maintaining, rightly enough, that such a fissure could not have remained open any considerable length of time. The real fact is, that there was a fissure, but often, only a very small one—from which a metamorphosing and replacing action appears to have emanated, extending to a greater or less distance, metamorphosing the neighbouring rock into a "capel," and impregnating it, by replacement, with oxide of tin. Where this is confined to a moderate width, and where the tin does not extend away in veins at right angles to the lode—the miner classes it all as "lode," and properly so; as to "walls," which some appear to consider the criterion of a true lode, they may, in these highly dislocated districts, be frequently met with *ad infinitum;* and in such deposits as those referred to, it is not unusual to find that half-a-dozen "wall" have been adopted in succession as the true wall of the lode, and abandoned. Nothing is more common than to be told on cutting into what was taken for the wall, "more lode was standing;" and in these classes of deposits the face ultimately adopted as the "wall of the lode" is that face beyond which the ground will not pay to be taken away.

I do not, of course, wish to imply by this that there are not many lodes wholly confined within the walls of an original fissure—lodes in the popular geological sense. I only wish to point out that there are many lodes of a different character; and this Pedn-an-drea deposit is characteristic and worthy of study, as forming a link between lodes of this class and those still more irregular deposits of tin ores called Carbonas in the extreme western districts of Cornwall."

* Henwood. *Met. Dep.* 1843, p. 232 and *Address p.* 4.

represent in cross-section a rich part accompanied by secondary veins. From a mechanical point of view the total opening ϵ which belongs to the principal vein, whilst there are neither feeders nor droppers in the zone of the branches, includes both those and the lodes. The good influence of the acuteness of the angle of junction in the case of a feeder is explained by the diagram fig. 2; the size of the vein$=\epsilon'$ but on meeting with a feeder whose width is ϵ'', the total width after the junction is ϵ. The increase $(\epsilon-\epsilon')$ is so much nearer to ϵ'' the less the branch diverges from the lode, *i.e.*—as the projection of ϵ'' upon the normal to the walls of the lode approaches nearer to the true size.

The variations of riches of the principal lode correspond to the coming together ("*unification*") or the separation ("*fractionnement*") of the disposable opening. It is also evident, that if the miner should work the mine overhead the droppers will become feeders, in which case the appearance of feeders will indicate impoverishment. Figs. 6 and 7, Plate III. shew an important lateral branch, which, instead of dying away in the country, reunites with the lode upon all its circumference and has thus formed a *horse*. The lenticular mass thus enclosed in the deposit often only appears to have suffered a little displacement, such as a slight rotation around its inferior border.* The *branches*, which we have defined in the first chapter, are elements of riches subordinate to certain profitable zones. Figs. 2 to 5 illustrate such branches, and not those unproductive ramifications to which the lode is subject in a bad kind of country.

Among the numerous circumstances which have influence upon the production of branches I would cite—the kind and relative thickness of the strata, their inclination (i), the dip (P) of the vein, its relative bearing (a); the pre-existing joints, and the effects of posterior movements due to the numerous upheavals. It would be incorrect to regard the general conditions (*allures*) of these secondary veins as necessary consequences of those of the principal opening. Nevertheless, among the determining causes it would seem that we should reckon the irregularities which the sinuous profile of the vein may present. The inflexions (Pr—Pm) are not constant. Let us separate those variations which are attributable to a modification in the inclination of the strata, and consider three contiguous beds.

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* When a horse occurs at the junction of two different rocks, the surfaces of contact in the part enclosed are exactly opposite to the corresponding parts in the walls of the branches. Henwood Address. p. 8.

The upper and lower beds are unfavorable, as being too hard, but their resistance is unequal; between them is a bed of good moderate hardness. The successive dips of the lode are in descending order P*m*., P*r*., P′*m*.; P*r*. being the greatest.

If P*m*. is less than P′*m*. we have (P*r*—P*m*) greater than (P*r*—P′*m*) then by the sliding of the hanging wall, the contact will be between the less inclined faces, *i.e.* those of the dip P*m* which belongs to the upper bed; the opening will moreover extend itself between the walls of the rich channel, but in the inferior bed itself the faces of the fissure inclined under the angle P′*m* may possibly remain separated. Inversely, if P*m* is greater than P′*m* the inferior pillar will come into action by preference, and will maintain a certain opening in the region P*m*. The preceding indications are in accordance with the facts observed, on the one side by general though gradual variations of size, on the other by the enriching influence of the relative underlies, but they also denote a new source of inequality from a new distribution of the weight, and from that a production of secondary openings.

Let us now examine some of the principal circumstances which modify, and sometimes even interrupt, the opening of the subterranean channels. The inevitable variations in the different profiles of the fractures oppose themselves through the descent of the hanging wall to an absolute regularity for any great length. They neither permit a rigorously parallel movement, nor an identical movement of different parts of the mass, so that at any given time, the region of the hanging wall may be considered to experience unequal depression on the run of the lode. If there has been an equal amount of fall everywhere it will have produced a gradual change of the opening ϵ of the erect parts in a longitudinal direction, if on the contrary the descent at certain points has been arrested, absolutely or relatively, this local interference will also shew itself in the opening of the fissure.

The cross-courses which cut through the country more or less normally to the veins facilitate the descent of the hanging wall in distinct sections. Without entering here upon the study of those phenomena of which the developement finds a place in the examination of the accessory rich parts, we will connect with them those "heaves" which a single lode in a single "country" sometimes experiences. We observe, in fact, in many mines certain fissures almost normal to the lode, and limited to the space between certain levels, neither extending to the surface, continuing in depth, nor persisting in length. These are simple rupturings of the rocks, or minor cracks contemporary with the Systems which they cross in direction. In approaching them the fissure may be abruptly interrupted, but veins may exist beyond, both right and left.

Elsewhere, the lode is said to be *spliced,* it narrows away little by little, and by cross-cutting on either side the miner finds it again without having traced any communication between the two thin ends of the lode.

We have, already, by implication, admitted here that the pillars are only subject to rubbings and some degree of fissuring, but, if for want of dimensions in the direction of the profile, or from want of resistance in the rock some pillars yield under the weight there results a fall, or "downthrow," which, being transmitted to a certain distance can only be fatal to the existence or the ulterior formation of subteranean channels, and by the disordering of the fractures obliterate in some degree the region, which up to that time seemed destined to be a rich part.

e. **Influence of the relative and absolute values of the thickness of the favorable and unfavorable strata, and of the amount of fault.**

The dimensions of the projections and channels measured upon their profile, *i.e.* upon the elements of which the underlies are P*r*. and P*m*., and of the amount of fault *h* (which is almost the same as the extent of the sliding H), are three numerical terms of which the absolute and relative values have much influence upon the existence, maintenance, and proportions of the subterranean channels. Let us admit that the inflexion (P*r*—P*m*) is in each case that which is most proper to favor the opening of rich channels, and at the same time to ensure their stability; we will then consider some extreme examples.

In the case of alternate good and bad beds which are *thin,* a small fault produces channels which are well defined, but narrow. In such a "country" and only considering lodes properly so-called and not cross-courses, they can only be thin.

As the amount of fault increases so as to be out of proportion with the thickness of the beds, there is a more and more complete opposition of walls of different quality, a descent of the projecting parts of the hanging wall into the next grooves of the foot wall of such a character that the channels become obliterated. Finally there is a destruction and crushing of the slightly projecting portions, resulting in the destruction of the elements which are most indispensable to the production of a cavity.*

The thin beds of the carboniferous formation clearly exemplify this order of facts, for the faults—already great—necessary to prepare large channels in the thick bed of great limestone, are only efficaceous in this bed, and we have seen that the still greater faults which have been observed in some of the north and south cross-courses, exceed the advantageous proportions.

Thick and solid† beds capable of lending themselves to motions which result in a tolerably large total opening ϵ, between good walls; such is the character of the rocks in connexion with normal rich parts of great extent. If the nature and formation of the rocks is exceptionally favorable to the resistance of the walls of the channels and the faces of the pillars—they must take the form of great *courses of ore* or large *shoots*—vast metalliferous deposits almost continuous in their size and riches; but should transverse interruptions have affected the descent of the hanging walls, the different portions of such zones will at least give a linear series of fine bunches in the plane of the lode.

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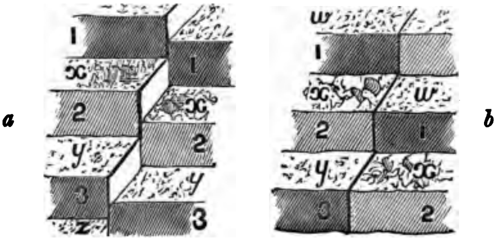
* Fig. 1 shews the effect of faults of different degrees upon the same fissure in the same "country," consisting of hard beds 1, 2, 3, and beds of medium hardness, x, y, z. In *a* the fault is just enough to produce good channels, in *b* it is so great that they are obliterated.



† I have already cited the remarks made by Mr. Smyth upon the lodes of the two first groups of Cardiganshire. He says, referring to the second (p. 657), "The slaty rocks.........exhibit on the whole a more massive bedding, in consequence of which it would appear that the mineral veins increase in width, expanding in some cases to upwards of 20 feet."

IV. Conditions of the lodes Fc and Fa—in plan, vertical projection, and profile.

In notes B and C I have given, with some detail, the calculations and geometric conditions which serve to determine the influence of the angular values a and i upon the relief and inclination of the groovings of the initial fracture. I will remark here, that in the first of these notes, I have taken by way of example a *cannelure* of which the faces are, one vertical and of good bearing, the other normal to the plane of the strata, *i.e.* a case almost exactly realized in some veins F*c*. I will not return to the values of P*m*, but I will summarise here the formulæ relating to the horizontal deviation.

A level opened in the normal plane makes with the direction of the beds an angle x, which is given in terms of i and of a by

$$(1)\quad \text{tang}\, x = \frac{\tan a}{\cos^2 i}.$$

The deviation $(x—a)$ is thus expressed

$$(4)\quad (x—a) = \text{arc tan}\left(\frac{\sin^2 i.\ \tan a}{\cos^2 i + \tan^2 a}\right)$$

For a given inclination i of the beds, the deviation reaches its maximum when the orientation of the system of fracture makes with the strike of the rocks an angle a_1 corresponding to

$$\tan a_1 = \cos i.$$

We have then the maximum

$$(5)\quad (x_1—a_1) = \text{arc tan}\left(\frac{\sin^2 i.}{2\cos i.}\right)$$

In Table IX, I give within about one minute of angle the values of a_1 and of $(x_1—a_1)$ calculated for inclinations (i) from 10° to 50°. The fourth column shews how rapidly the deviation increases with the inclination.

TABLE IX.

Normal plane corresponding to the maximum of deviation; bearing a_1; deviation $(x_1—a_1)$.

i	a_1	$(x_1—a_1)$	Increase.
10°	44° 34′	0° 53′	......2° 41′
20	43 13	3 34	...4 39
30	40 54	8 13	......6 43
40	37 27	15 6	
45	35 16	19 28	...9 26
50	82 44	24 32	

Let us take the numbers of the third column as simple indications, such as we have made for the figures of Table VII relating to inflexions (P*r* — P*m*); and—without entering anew upon a discussion of the variations which the projections of the *cannelures* owe to the differences in quality of the strata, we may remark that the maximum of $(x_1—a_1)$ only relates to the normal plane, and that it may be exceeded in many cases among lodes F*a* and sometimes even among lodes F*o*.

Inclinations of from 20° to 30° are frequent in Cornwall, so also are the deviations or *turns* of 5° to 7° mentioned by Mr. Chas. Thomas, which suffice to convert a rich lode into a poor one. Whenever i varies between 30° and 45°, the deviations may amount to from 8° to 20°, whilst a_1 is reduced from 41° to 35°. If the strata consist of alternate beds offering unequal resistance to rupture—some being very hard, and if i and a happen to differ but little from the values already specified, it is probable that great angular deviations will have taken place, so that the lodes will present some rather abrupt bends.

The western border of the granite mass of St. Just is separated from the ocean between Porth Just and Pendeen Cove by a narrow band of felspathic schist alternating with beds of greenstone. Cape Cornwall is composed of these rocks as well as the cliffs of Boswedden, Botallack, and Levant.* The marked zigzags which characterise many of the lodes of this district are not the least interesting of anomalies, and they appear to be connected with the mutual occurrence of the natural conditions which we have just enumerated.

Note C is an explanation of the diagrams on plate V, where a lode F*o* and another F*a* are placed side by side—both having been produced in the same rocks under the influence of the same system of fracture.

In these illustrations I have chosen tolerably large values, so as to shew better the inflexions and deviations, and to bring out the contrasts between F*o* and F*a*. If we were to give smaller values to a and i, we should see the favorable zones lying almost horizontally and their deviations lessened; in this way we should approach the cases most frequently observed in the E.N.E. lodes of the principal districts of Cornwall.

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* "Eight beds of slaty felspar rock and a like number of the hornblende or greenstone rock. The dip of all these beds is north, with an inclination varying from 20° to 40°.........great uniformity of dip and direction."—J. Forbes on the Geology of Land's End District. Trans. Roy. Geol. Soc. Corn., vol. 2, 1822, pp. 255-6.

I have limited myself further to the discussion of some essential points of the preparatory traces—fig. 3 and 7, pl. IV, and of the diagrams properly so-called in pl. V.

The beds, alternately good and bad—are supposed to be of equal thickness; their inclination $i=40°$.

The System of fracture makes an angle $a=32°$ with the direction of the beds. The difference ($Pr—Pm$) of the underlies is supposed to be equal in the two lodes F*c* and F*a*. The *cannelures* of F*c* are defined by taking for the steepest face $Pr=82°$, and—for the less steep face a plane normal to the strata; we find that its dip is $Pm=58°$, consequently we have $(Pr—Pm)=24°$. As to the lode F*a*, the dips are also $Pr=82°$ and $Pm=58°$, but they have a contrary direction.

The horizontal deviations are about 10° 30′ (F*c*) and 13° (F*a*) and the mean directions 5° for F*c* and 8° for F*a* on one side or the other of the orientation of the System of Fracture; their bissectrice making with the system an angle of only 1° 30′.

The mean dips are about 71° (F*c*), and 66° 30′ (F*a*.)

We remark that the intersection or the junction of the two lodes dips in the same direction as the beds, and note in passing, without touching upon the study of the accessory riches due to the coming together of two lodes, that it is easy in the case of lodes F*c* and F*a* of the same system to understand the character announced by Mr. Henwood.* "Lodes are often rich at their junctions, especially if they come together either horizontally or vertically at an acute angle." According to our diagrams—the two lodes would come together in a good bed under a very acute angle; horizontally the angle would be theoretically nothing—and vertically it would be 16°. In a bad bed, on the contrary, they become respectively—in the levels, 23° 30′, and in the winzes about 60°. We may add that if the junction is rich the dip of this rich zone will be in the same direction as that of the rocks, and this fact contributes to the generality of the third character (1st Chapter).

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* Address, p. 11.

The plans fig. 1 and 5, Plate V, are based upon a knowledge of the mean plane of the lode. The line XY is taken parallel to the mean direction, an auxiliary plane perpendicular to XY gives the profile of the lode. The projections correspond to what would be the plan and the longitudinal section of the mine.

The shading distinguishes the steep from the flat faces of the fracture, and shews what would be the configuration of the rich parts, apart from their width supposing the perfect regularity of the phenomena.

The equidistant horizontal tracts numbered from 0° to 70° represent levels upon figures 3 and 7; their separation is made to correspond with the plans, figs. 4 and 8, and should not be regarded as a scale of the thickness of the beds.

We also observe upon the plans, figs 4 and 8, the character already referred to of the levels coming together in a rich zone—and separating when they pass into a sterile region. The zones or columns A, B, C, D, are parallel to the edges of the *cannelures.* In plan they make (F*c*) angles of 8° 30′, (F*a*) angles of 11° 30′ respectively, with the mean directions. In vertical projection they are inclined somewhat differently to the horizon (23° for F*c*, and 26° 30′ for F*a*), besides, they are much nearer together in the lode F*c*. For an equal development of the workings in length and depth, the surface of the rich bands of the lodes F*c* is more than double the corresponding surface in F*a*.

We have already seen that the lodes F*c* (dipping towards the granite) are more frequent than the others; if they had been also always richer, they would have been worked in preference to the lodes F*a*. This is not so, although, as compared with good lodes F*c*, of which the enumeration would be very long, we may count a considerable number of lodes of the other group. In each locality, the thickness and relative resistance of the beds which we consider as destined to form the walls of channels and the faces of the pillars, are the elements which favor one or other of the groups F*c* and F*a*; it is the same with the slippings in each direction, and particularly the movements of the rocks due to the different systems which have contributed to the re-openings and the metalliferous fillings.

In the best districts in Cornwall the inclination i is moderate—the angle a is small; the normal rich parts may lead to *fine courses of ore*, the axes of which are but little inclined as viewed in the plane of the lode.

After a period of great prosperity mines opened upon such deposits (gites) are exposed to poverty, even to sterility if sinking has been discontinued, exploration of the lateral lodes neglected, or unfruitful, and if the accessory riches are insufficient to sustain the production, until the lode has again penetrated in depth into suitable strata.*

The lodes Fa present in this connection a marked disadvantage, since they traverse at a small inclination, thick beds of bad nature; the unproductive zones consequently assume disastrous proportions.

The perseverance of the exploitant is put to a very severe test, for not only are the levels long in the poor zones, but what is worse the inclined shafts or winzes areso flat that the sinking and are expensive in men and material.

It would be easy in Cornwall to cite mines of which the temporary abandonment has been due to no other cause than this.

a. Changes in the Underlie of Lodes.

Some few examples are known of lodes changing their underlie in different parts of their course.† It will be interesting to seek in each case the probable origin and effects of this kind of anomaly. One is led to distinguish between the inversion due to a junction of lodes, or that due to a change of rock, from that which is produced when the lode continues in the same "country." The examples of the first group will be more properly studied as accessory riches. I will here consider only an isolated lode in a single containing rock.

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* Mr. Henwood remarking upon the variations in the size of lodes in depth, says (Met. Dep. 1843, p. 244) that when he visited Dolcoath, the Consolidated Mines and many others, the deep levels were all poor, the lodes in general becoming thinner and flatter. He cites on this subject a remark of M. Burr in the Mining Review for 1836." Many mines have been alternately worked and abandoned, the abandonment resulting from coming upon unproductive masses of the vein which were regarded as the definite limits of the metalliferous region. To this sterility, which has been supposed without remedy, has often succeeded new riches.

† Address, p. 6.

The principal lode (*Standard lode*) at St. Ives Consols[‡] bears E. 25° N., the mean dip P. is almost exactly 90°, *i.e.* it is almost vertical; the "country" is granite, generally coarse and porphyritic. The cross section passing through the engine shaft shews the principal inversions. From the surface to the 47-fathom level below adit (which is 20 fathoms from grass) the lode dips north; from the 47 to the 107 it dips to the south, from 117 to 167 it again underlies north, and finally the southward underlie is resumed from the 167 to the bottom (177). The mean angular variation from the vertical on either side is about 8°, while the actual variations are generally between 4° and 12°, but occasionally 18°, or even 28°. Their differences seldom exceed 24°, and are often from 14° to 16°. Without insisting upon this example, I would here remark that bearing in mind the verticality of the mean plane, the form of this opening has nothing abnormal. The lode has been productive for a great length, and especially in the portions contained between two cross-courses; the mean thickness is about 2′ 6″, but increased in places to 4′ 0″, 6′ 0″, or 8 feet; the thinnest parts appear to have a northward dip and *vice versa.*

The Wheal Gwens lode at Wheal Union, in the same district, shews the influence of the encasing rock still better. I extract the following particulars from Table XV of Henwood's *Metalliferous Deposits*, 1843. The mean direction of the lode is E. 15° N.

TABLE X.

Depth in fathoms.	UNDERLIE.		Size in inches.	Nature of Granite Country.
	Direction.	Amount.		
22	S.	86° to 90°	10″	Very large grained.
30	S.	82 to 84 hanging wall of the cross-course	4	———
	N.	82 to 86 foot wall	6	Fine grained.
48	S.	84 to 86	10	Medium.
53	S. to N.	80 83	6 to 12	———
63	N.	84 to 90	7	Coarse grained.
	N.	48 to 56	1	Fine grained.

[‡] Met. Dep. 1843, Table XVI. The Standard lode is there described to a depth of 135 fathoms. In the *Mining and Smelting Magazine* 1863, vol. iii, p. 140, there is a description and figures of the works which at that time had reached a depth of 200 fathoms from surface.

The thickness of about 10″ which is favorable to riches is met with in the parts inclined southward, and contained in large or medium grained granite. The fine-grained granite which occurs at the first inversion of underlie at a depth of 30 fathoms, and also at the 63-fathom level, occurs with a thin and poor lode dipping northward.

Let us compare with these tin lodes in granite a copper lode in greenstone.

The principal or *Main Lode* at *North Roskear*, near Camborne, of which the direction is nearly E. 40° N., traversed from the adit level (30 fathoms from surface) downwards a mass of greenstone for about 100 fathoms in depth. The workings were in 1858 carried to a depth of 267 fathoms from surface. Below the greenstone the country was killas, cut through by two elvans. The lode underlies distinctly to the south east. Mr. Henwood* describes a zone of lode in the midst of the greenstone between the depths of 57 and 137-fathoms levels. From the 57 to the 97, the lode dips sometimes northward, sometimes southward, while it is in some places vertical. Below the 117, the dip is distinctly south and varies from 60° to 65° . . . . . 80° . . . . . 84°. The rock is everywhere hard, but at certain levels it is intensely hard; one part of the northward dip occurs in this very hard rock. Variations in size are frequent, the widths of 4 ft., 5 ft., 6 ft., and 7 ft. are met with in parts where the southerly dip is between 80° and 90°, whilst the inclinations of 60° to 64° in the same direction give a lode reduced to 6″, 4″, or 1″. With the northerly dips of 68°, 77°, 82°, and 86°, the lode is from 12″ to 24″ wide, but quartz and the silicified débris of the "country" abound there more than copper pyrites.

The expressions P*r*, P*m*, and the angular difference (P*r*—P*m*) cannot be properly employed for the study of the profiles of such lodes; however, in every case, the *cannelures* appear to result from the unequal resistance which the beds of rock have opposed to rupture; an opening of the channels is also produced by the descent of the hanging wall, but the effects of this movement are more complex, because in the zones where the slope is in an opposite direction to the mean underlie, the hanging and foot walls of the lode may be regarded as occupying inverse positions. Thus, in the lode of North Roskear, the south side of the lode constitutes the hanging wall, even where the lode dips occasionally to the north. An attentive examination of those parts which have served as pillars of sliding, enables us however, as in ordinary cases, to determine the probable amount of opening which will occur in the most favorable zones of the fracture.

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* Met. Dep. Tab. LV.

b. Change of the direction of the dip *i* of the rocks.

In grouping the lodes under the designations F*c* and F*a*, we have remarked that the beds of schist and of granite, in spite of certain disturbances and undulations, are on the whole tolerably regular, so that in general, upon the course of the lode, the dip of the encasing rock is not subject to any change of direction.

In some exceptional cases, however, the same lodes, in consequence of plications of the strata previous to the fracture, might belong at different points, to each of the groups F*c* and F*a*; contrary to the examples already mentioned it is no longer P, but rather *i*, which has been reversed. The killas rests almost everywhere upon the granite, consequently the lode F*c*, whose dip is opposite to that of the rocks, dips *towards* the granite; some reservations must however here be made.

Upon the northern slope of the granite outlier of Carn Brea, the workings of many mines situated between Camborne and Redruth have shewn the existence of subterranean ranges of granite hills, whose bearing is E.N.E. like the mass itself. Two ridges are at present known; the first has been observed to the eastward in Dolcoath Mine,* and westward between Carn Brea and East Pool; a second ridge has been observed north of the first in the vertical shaft of East Pool, at a depth of 135 fathoms below the adit. The cross-sections Pl. VI, shew the position and relative importance of these ridges.†

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* See the transverse section of Dolcoath in the "*Remarks*" of Capt. Chas. Thomas; also the sections by Capt. Maynard in the Reports of the Miners' Assoc. for 1873 and 1875.

† Mr. H. C. Salmon gave in the Mining and Smelting Magazine, vol. I, 1862, plate V, a section of these underground ranges of granite. In 1866, Mr. W. S. Garby, the able Manager of East Pool, was kind enough to allow me to examine plans and cross-sections of the mine on a scale of 1″ to 8 fathoms, which had been most carefully prepared by Capt. Maynard. M. Lodin, student engineer of mines, who visited East Pool in 1873, brought me an addition to the sketch, which I have figured. The supposed surface of the granite is still drawn in rounded ridges, but the projection proves to be less considerable than was supposed at first.

It was upon reaching the granite, that at East Pool, a large lode of copper pyrites, oxide of tin, wolfram, and iron pyrites was met with, which formed a junction with the principal lode (*main* or *engine lode*) by a simple dropper from the foot-wall. The main lode dips to the south, *i.e. towards* the mass of Carn Brea, but when in depth it comes in proximity to the south flank of the second ridge, it may be regarded upon a certain zone as receding from the second ridge, whilst the new or *great lode* dips north, or *towards* the centre of the new ridge. In 1866, they had reached a depth of 170 fathoms, and shafts were sunk vertically between the two lodes, both of which were large and rich in the granite.

As to the killas, it would be interesting to know to what extent its beds bend over these bosses of granite. The workings of the mines in this district answer without doubt the principal questions relating to the subterranean surface of the granite in Cornwall, and this solution in the Camborne Mines must one day have an influence over the future of other districts.

c. Bad influence of contortions of strata.

If the regularity of the normal rich parts depends upon that of the country, it would seem natural to reckon but little upon the metalliferous lodes of a district where the strata are greatly curved and contorted. But if, in addition, we have the presence, at certain points, of thin beds which are alternately too hard and too soft, we may be almost certain that in these regions only very thin lodes will exist, whilst the normal rich parts throughout the whole district will exhibit a want of continuity; consequently there will be neither great *courses of ore*, nor long uninterrupted *shoots*, nor a linear series of fine *bunches*. The continual variations of a and i are opposed to the production of continuous *cannelures*, and when the descent of the hanging wall took place the irregularity of the successive profiles of the fracture corresponded to no less irregular movements of the rocks; the normal riches will therefore consist of a series of small lenticular masses, more or less elongated, some of which may possibly be grouped along certain axes in the plane of the lode.

In such mines there would be a certainty of unpromising works, subject to frequent abandonments; for the *accessory riches* might stimulate research, but would not make up for the little value of the normal riches.

The mines in the neighbourhood of Gwinear may serve for examples. The district of Gwinear and Crowan consists of schistose strata, which in the east rest upon the western flanks of the great granite mass of Carn Menelez; to the south on the granite of Godolphin Hill; while towards the west, in the direction of Phillack, the mass of St. Ives forms, if not the limit, at anyrate the horizon. The schists are traversed by numerous elvan dykes, by many lodes properly so-called, bearing nearly E.N.E., by still more numerous *caunter lodes* running to the N. of W. and making angles of about 45° with the preceding, and by certain cross-courses. Wherever they have been explored so far, and especially in places remote from the granite, the strata have proved unfavorable both for copper and tin. This is the judgment of Capt. Chas. Thomas.* Mr. Henwood has devoted to this district one chapter of his *Metalliferous Deposits*, and ten tables descriptive of as many mines.† I would refer the reader to this description, noting especially what is said of Herland.

The killas is schistose, containing numerous globular concretions, and at Herland nodular masses of granite. The inclination of the strata is in general to the north or north east, but they are frequently curved and contorted. The elvans bearing almost north east vary very greatly in size and dip; some contain, in a finely disseminated state, enough of metallic mineral to pay for extraction; such as the stanniferous elvan at Parbola, and the elvan forming the south lode at Relistian, which contains oxide of tin, copper pyrites, and iron pyrites.

According to Mr. W. Phillips, "most of the east and west, or metalliferous veins of Herland and Drannack Mines, varied from 2 to 6 *inches* in width, and, whenever found to exceed the latter size, it proved an indication that they were about to diminish, and in the language of the miner, to pass away in the run of some fathoms in mere strings.‡

"The copper lodes of this district," said the Rev. Malachy Hitchins "are remarkable for the shortness of their continuity; for, whereas other lodes may be traced to an indefinite extent in the same line of direction, these, on the contrary, are observed to taper away gradually, and terminate to all appearance at a short distance, completely and irrecoverably."*

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* Capt. Chas. Thomas Remarks, p. 19.

† Met. Dep. 1483, pp. 35 to 42, and Tables 33 to 42.

‡ Geol. Trans. 11, O.S. p. 147.

Mr. H. C. Salmon says of the same district.† "It is essentially a copper district, that metal "making" in connection with elvans, and although it has been fairly productive, yet on the whole it has been economically the worst district in West Cornwall, from the extremely bunchy and uncertain nature of its metallic deposits."

V.—*The Sterile and Metalliferous North and South Cross-courses.*

The principal cross-courses in Cornwall make with the east and west lodes an angle near to 90°, and nearly always more than 60°. The name *cross-vein* includes lodes of argentiferous galena, of oxide of iron, of quartz containing little or no metallic substance, and of clay *(flucans)*. Other interruptions called *slides* are faults whose bearing is nearly that of the east and west lodes, they cut through the schists of certain districts; in general their dip is less than 60°. As they have been only observed in a few places, they need not be further referred to here.

We may consider the north and south cross-courses as forming an important group of veins, of which the conditions vary much from those of the east and west lodes. The study of their intersections and the influence which many cross-courses exert upon the riches of the lodes intersected, must be reserved for another work; we will examine here the characters of the single vein in a single containing rock.

The cross-courses have inflexions and variations like the lodes,‡ but in a less degree. In some cases, however, the same cross-course has in different parts of its course very different bearings. Whilst a change in the size and underlie of a lode is usually accompanied by a change in its composition, *no such modifications are observed in similar cases with regard to the cross-courses.* Though still irregular, the underlie of the cross-courses is in general about 80°, being much greater as well as less variable than that of the lodes. Briefly, the cross-courses depart less than the lodes from their mean planes, and these latter are more nearly vertical.

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* Phil. Trans. 1801, p. 159.

† Mining and Smelting Magazine, 1864, vol. V, p. 329.

‡ This description of the characters of cross-courses is in some degree a résumé of Mr. Henwood's Observations. *Met. Dep.* p. 254-281, and Address, p. 13.

Each cross-course has a characteristic size, of which the variations are gradual and limited; the size in general is much more constant than in lodes. The mean width of the cross-courses in Cornwall is about 4 feet, which is greater than that of the lodes. The mean underlie is usually maintained, although the cross-course may pass into a country of a different nature—its direction also remains the same; still each district furnishes some exceptions to this rule.

Leaving for a time the consideration of metalliferous cross-courses, we find that the cross-veins participate in the nature of each rock traversed,* being called cross-courses where quartz predominates, and flucans where composed of clay. The same cross-course may receive successively each of these names in different parts of its course, or it may at the same point be composed partly of quartz, partly of clay, either mixed or in distinct veins; which however, seldom retain their respective situations for any great extent.

Fragments of the enclosing rocks fractured in different degrees by mechanical forces are met with in the sterile cross-courses, where the chemical effects due to the circulation of water are naturally less developed than in the metalliferous veins, and more often subordinate to a partial alteration of the rock or to a quartzose deposit. The contrasts observable between the two types of cross-veins are most observable in the schists. In a *homogeneous* killas, the cross-veins are generally composed of argillaceous substances, these are the *flucans*. But in killas abounding with quartz veins (*country branches*) they are more quartzose than elsewhere; these are the *cross-courses* properly so-called. In their neighbourhood the rock is often traversed in all directions by little veins of quartz. Some portions of the "country" are frequently surrounded by the quartz, which has impregnated and penetrated the walls, exactly as in some metalliferous veins; in such cases the quartz of the cross-courses is compact. But often on the contrary the quartz is crystallized in irregular prisms, disposed horizontally, and normally to the walls and the joints. Such crystals ("cross-course spar") are recognized in all countries as an indication of sterility.

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* Where a cross-course traverses china clay, (decomposed granite) however, it is nearly always rocky, quartzose, or schorlaceous.

On this subject, Mr. Henwood remarks that the parts of the lodes yielding most crystals are in general of homogeneous composition, and rarely contain an abundance of foreign substance, and that the existence of these crystals seems to exclude the possibility of a mixture with the materials of the "country," so that the prisms of quartz are scarcely attached to the walls. I believe that this crystallization is an indication of the purity (*i.e.* the sterility) of the siliceous waters,* and of the tranquillity of the period of its deposition. Comparing the bearing of the cross-courses with that of a group of important joints in the surrounding rocks, Mr. Henwood shews that there is a remarkable coincidence, from which it results that the structure of the cross-courses is particularly characterized by an abundance of joints.

These joints vary a little in direction and in dip—they divide the cross-courses into subordinate veins of variable width, they also form distinct selvages on the hanging and foot walls. Sometimes this veined structure so greatly predominates in the neighbourhood of cross-courses, that the rock presents, laterally, for many fathoms an alternation of veins of quartz, and veins of rock,† which intersect each other mutually, both in length and depth. In this region the rock is usually much decomposed and softened by the action of the water which circulates in the cross-course; sometimes, however, if the rock is killas, it retains its structure.

This band in the neighbourhood of the cross-course, often many fathoms in width, is what is called by the miners "disordered ground."

The heave of lodes by cross-courses is not always a mere displacement of the extremities of the lode, on the contrary, a very interesting complexity is often observable, as well as the production of new branches which are often important; again, we may note here that the mean extent of the heave of lodes by cross-courses, properly so-called, is only one half of that effected by flucans. We may mention finally that cross-veins appear to be more rare in the granite than in the schist, and, like the lodes, the majority dip towards the granite.

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* Mr. R. W. Fox (On Mineral Veins), p. 120-121), supposes that this crystallization indicates an electrical action between the two walls of the fissure.

† This banded structure in a *metalliferous* cross-course is especially well seen at Restormel Iron Mine. Here the cross-course (lode) bears nearly magnetic north, and underlies about 1¼ feet in a fathom, eastward. In July, 1876, I counted at Restormel Mine, no less than 36 distinct bands or veins of quartz, varying from 1-16th of an inch to 12 inches, alternating with bands of oxide of iron from 1″ to 6 feet wide; many of these quartz veins were continuous for 20 or more fathoms in length. This was at a depth of 12 fathoms below adit.—J. H. C. —See also note on page 88 with reference to this cross-course.

a. Circumstances under which the north and south cross-veins appear to have been formed.

Among the eleven ancient systems, five belong to a north and south group; these are la Vendée, Longmynd, Forez, and, at a considerable interval, North of England, and Rhine. In the following table, I have associated these systems in two groups, together with the perpendiculars of the six east and west systems.

TABLE XI.

NORTH AND SOUTH GROUPS.

West of North.			East of North.		
Vendée		26°	Longmynd		20°
Forez		23	Rhine		10
North of England		8			
The perpendiculars of the east and west Systems, are	Finistère	22	Perpendiculars of the east & west Systems, are	Morbihan	36
	Westmoreland	40			
	Land's End	8		Ballons	5
	Pays Bas	15			

The very ancient system of Vendée and the Forez system make a very small angle with each other, and are very nearly perpendicular to the system of Finistère, whilst that of the North of England is almost exactly perpendicular to the Land's End system. Without carrying this comparison further, it is evident that the systems of cross-veins posterior to the Devonian formation, have found the rocks well prepared, and have often followed the lines of least resistance already weakened by the normal joints.

Most of the cross-veins of Cornwall may then be regarded as cutting, not only the lodes, but also the strike of the rocks nearly at an angle of 90°, and from this fact, that they *cross* the "country," results the properties already described.

Theoretically, supposing a tendency for a mass of strata to be broken in a direction *exactly* perpendicular ($a = 90°$) to its strike, the fracture would be a vertical plane. In fact, in Cornwall the mean dip being near 80°, the fracture is rough, but the flutings produced have little depth, because the inclination i of the rocks is but moderate.*

The angular differences of the successive dips often fall to 6° or 10°, and inversions of underlie are less rare than in the lodes. But the greatest obstacle to the formation of regular channels proceeds from the want of stability of the pillars, which being already fissured by parallel joints, offer no resistance, and are therefore liable to be carried down by the descent of the hanging wall.

When the rocks are homogeneous, *flucan* will naturally be formed, for other things being equal, the more complete this homogeneity the less likely is the fracture to be rough, and the less opposed to a motion of the masses; and it is this motion which, if sufficiently prolonged, produces the flucan by grinding up fragments of the country.

In the less homogeneous quartzose schists, the surface of rupture is more unequal, and if there was not a too violent motion at or near the period of fracture, the circulating waters would be able to cover the walls with a siliceous coating, so preventing the production of plastic material and the obstruction of the narrow subterranean conduits; and commencing the formation of the quartzose cross-course. As to the increase of the veins of each type, we observe that in argillaceous cross-veins or flucans, the initial descent having almost completely obliterated the fissures, the action of the waters is in some sort confined to the transport of very fine particles, which tend to stop any further access of mineral matter. If the movement of descent should be renewed, whether slowly or rapidly, it would only reproduce these phenomena—augmenting laterally the mass of the flucan without changing its character. For the quartzose cross-course on the contrary, the movements must have been always slow, and in cases of repetition they must have been separated by intervals of rest which have favored the crystallization of the quartz; similar operations have taken place in a great number of secondary veins as exhibited in lateral zones.

If a somewhat abrupt sliding motion should be produced, a vein of flucan might be formed partly between and partly through the layers of quartz already deposited. It is a well-known fact* that the veins, whether lodes or cross-courses containing clay, ("flucany") *cut through* those which are destitute of such matters, the flucan being the result of motion, and often facilitating future motions.

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* If the inclination of the strata exceeds 50°, and the angle a falls to 70° or 60°, the fracture may depart considerably from its mean plane. The Snailbeach lode, fig. 4, plate I, is a case in point. See also on this subject, Note B.

d. Examples of Metalliferous Cross-veins.

Lodes which bear nearly north and south, and contain either argentiferous galena or oxide of iron, are met with from time to time between the neighbourhood of Exeter and the extreme west of Cornwall, but they do not all in the same degree deserve the name of metalliferous cross-veins. We will choose as examples the lead lodes† which occur in the Devonian schists to the south of Liskeard, especially considering the principal characters which illustrate the essential differences of structure between these veins and the east and west lodes already studied. The country dips in general pretty regularly to the south, or south a little east, at an angle from 5° to 15°; the killas is of a bluish black color, homogeneous, and pretty hard in those parts of the district favorable to lead lodes. The hardness is still greater at a depth of about 150 fathoms. In the killas masses of rock locally, but improperly, called elvan, are intercalated; these are a kind of very felspathic diorite, compact or fine-grained, and tolerably hard in depth. The presence of this rock in the neighbourhood of the lode is by no means unfavorable.

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* R. W. Fox, *On Mineral Veins*, pp. 88-89. I would add that the great *Master Lodes* or *Champion Lodes* in which the miners have the least fear of perturbations, do not escape the action of flucans. Mr. Charles Thomas shewed me a heave of 4″ to 6″ very clearly upon one of the walls of Dolcoath, produced upon this quartzose stanniferous lode of nearly 21 feet wide, by a very thin flucan.

† The Iron Mines of Restormel, near Lostwithiel, have long been worked, at first near the surface, on two parallel lodes for a length of nearly two miles, more recently the workings have been chiefly on one lode. The mean direction of these lodes is N. 15° W., and the dip is from 70° to 85° eastward. The present depth of the mine is 12 fathoms below the deep adit, or between 60 and 70 fathoms from surface. In the prolongation of this deposit, the Ordnance Map shews an iron lode bearing 6° west of north, and running from Black-pool to Balscalt, eastward from Bodmin. From this point to the southern extremity near Lostwithiel, the distance is nearly 3 miles. In 1858, the underground workings, from 50 to 60 fathoms below the surface, were reached by a cross-cut adit level 240 fathoms long, which continued by the side of the lode for 500 fathoms; in this part of the lode the direction was N. 2° to 4° W. At less than a mile to the west is the eastern side of the St. Austell granite mass, so that at Restormel the strike of the schists is N.N.W. More to the north the curving of the rocks corresponds to a bearing of N.W., and at last, near Bodmin the schists

One of the most interesting lodes in this group is that worked on the two contiguous mines of *Trelawney* and *Huel Mary Ann*, the former being north of the latter. Having visited Trelawney in 1858, the facts stated below relate especially to this mine, but according to the very complete descriptions of Mr. Henwood, and the notes of Mr. H. C. Salmon, upon which I rely,* a great many of the characters of this vein re-appear, it seems, in the lode at *Herodsfoot*, situated more to the south. The lode at Trelawney and Mary Ann has been opened upon for a total length of nearly a mile. At Trelawney the bearing is N. 5° W., and at Mary Ann, N. 3° to 8° E., coinciding accurately with the directions of the principal joints, which vary from N. 12° W. to N. 8° E.†

Two faults cut through the lodes; the bearing of the first is W. 32° to 37° N. and the underlie southward; that of the second W. 22° to 28° N. and the underlie northward. The latter has limited the working of Mary Ann towards the south, and the

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under the influence of Bodmin Moor dip to the south. The lodes properly known as Restormel therefore make with the strike of the surrounding schist a very acute angle *a*; *i.e. they do not cross the strike of the rocks.*

On the other hand the N. and S. and N.N.W. lodes which are called *guides*, in the St. Just district, and which are rich in oxide of iron, form useful junctions rather than intersections, with the W.N.W. and N.W. lodes. Mr. J. CARNE (*On the Mineral Productions of St. Just*), cites the *Narrow Guide*, which by its junctions with the "Huel Button" copper lode at Botallack produced a rich deposit of copper on the part called the "Crown Lode," and which a little more to the south gave with the Parknoweth tin lode an immense quantity of oxide of tin; the same *guide* would cut the Huel Owles tin lode still farther southward, and at this point, on the contrary, their being no junction the riches came to an end. Mr. Henwood (*Met. Dep.* p. 10), in confirming Mr. Carne's observations, said "in many cases, although the *lode* has continued rich in actual contact with the cross-vein, it has never been discovered on the other side.

* *Met. Dep.* 1871, pp. 699 to 720, and Tables 27—29; *Mining and Smelting Magazine*, vol. 11, 1862, pp. 211 to 222.

† The lode at Herodsfoot bears N. 8° to 12° W., and dips 80° to the east. It would not be difficult to find the following directions in the lodes of Liskeard.

North of England	N. 8° 7′ W.
Perpendicular to Land's End	N. 8° 23′ W.
Rhine	N. 10° 26′ E.

This latter system is clearly marked in the lodes of galena, having a gangue of fluor spar which are worked upon the banks of the Tamar. According to the Map of the Tavistock Mining District published in 1859, by Mr. C. Williams, the mean directions of the Beeralstone lodes are:—

Tamar Mine	N. 3° E.	The underlie is Eastward.
South Tamar	N. 9° E	
East Tamar	N. 9° E.	
Great Tamar	N. 11° E. N. 13° E.	

explorations made in the broken and slidy ground in the neighbourhood of the fault have been unprofitable.

The mean dip of the lode is 78° to 79° towards the east, the parts having greatest underlie are inclined 70°, 68°, or occasionally only 64° from the horizontal, while those nearest the perpendicular make angles of 86°, 88°, or 90°; there are indeed some local inversions where the dip is towards the west.

The mean size of the lode is about 2 feet, and it varies in width from 6 inches to 4 feet; in some places it is composed of numerous subordinate veins.

The lode is accompanied by a well developed siliceous selvage or *capel*, which is very remarkable on account of the appearance of the quartz and its brecciform structure. The quartz is white and porcellanous, and it encloses fragments of black killas, having sharp edges and appearing to be silicified, as shewn in the figure in the note below. In the stopes at Trelawney, I have seen this breccia from 3 to 4 feet wide. Mr. Henwood says "it rarely extends more than 4 or 5 feet from the lode, and it never contains much galena; it occurs more often on the foot wall than on the hanging wall. *Contrary to the common opinion as to a similar structure in a copper district*, this breccia is considered as a favorable indication in the whole of this lead-bearing district.*

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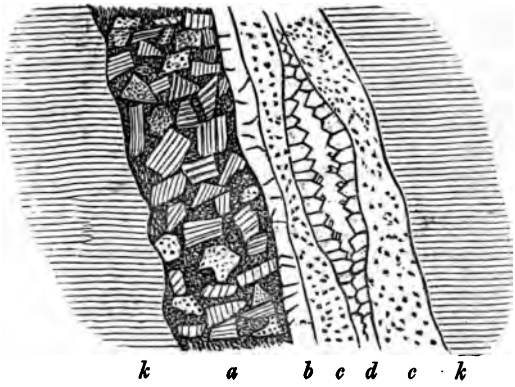
* The following figure from Dr. Le Neve Foster's account of the lode at Huel Mary Ann, is a cross-section of the lode at a point where the brecciform capel is found on the foot wall, as shewn at *a*; *b* is a band of vitreous quartz; *c c* are bands of chalcedonic quartz known as "cab"; and *d* is a band of crystalline quartz containing many "vughs"; *k k* is the killas.—See Trans. Royal Geol. Soc. Corn. Vol. IX, pp. 155.



I will add as a contrast to the preceding remarks, that the encasing rock is here harder in the immediate neighbourhood of the lode than at a distance of some fathoms, whilst nearly everywhere else when a cross-cut is driven in search of a lode its nearness is indicated by a softening of the ground. It would seem almost evident that the silicification of the rock and the formation of the quartzose breccia having from the first prepared a particularly stable cavity, the obliteration of the vein or its transformation into flucan has here been prevented; not only have the walls been consolidated, but new surfaces still more solid have been provided by the thick quartz breccia. From the variety of minerals contained in this lode,* it is probable that the filling was continued during many geological periods.

Fine crystallizations were also frequently met with in cavities or "vughs." In 1858, some of the levels at Trelawney laid open magnificent vughs which continued open for a great length at the backs of levels, rising almost vertically to a height then undetermined.

The mineral was not equally distributed throughout the lode, it was especially abundant in those parts which were most nearly vertical, and appeared concentrated towards the middle of the lode. The rich parts did not occur as well-defined columns or *shoots*, on the contrary they consisted of a series of little lenticular masses connected by threads of mineral. Moreover, in spite of the regions disturbed by the east and west faults, the almost contiguous workings have included nearly the whole of the lode. The workings have been carried to a depth of 256 fathoms, and the lode proved productive at Trelawney for nearly 500 fathoms in length, and at Mary Ann for about 300 fathoms in the lower levels.*

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* At the outcrop in the region north of the lode there was gozzan, in the upper levels carbonate and phosphate of lead were found; lower down with the galena there was pretty much iron pyrites, with a little blende and copper-pyrites. The presence of this latter mineral appears to be a favorable indication of richness in silver. The average proportion of silver per ton of dressed mineral varied in different parts of the workings from 35 ozs. to 66 ozs., and the general mean would be close upon 50 ozs. As to the earthy gangues the most abundant after quartz was fluor spar; barytes occurred in quantity about the 40-fathom level, and more rarely down to the 80-fathom level, while carbonate of lime especially occurred in the lower levels. These two latter substances are generally scarce in Cornwall, but they occur largely in other mining countries. In 1858, at Trelawney Mine 100 tons of mineral raised, yielded when dressed 8 to 8½ tons of merchantable ore.

Thus, these straight lodes having few undulations, a great angle of dip, a width subject only to gradual variations, and a disposition of metallic contents which seems more regular in cross section than longitudinally, form true types of lead bearing, cross-courses; we see clearly in what manner their general characters (*allures*) differ from those of the lodes of copper and lead belonging to the east and west class of Cornish lodes, and also that they deserve to attract the attention of the miner; but when we once recognise to what a concourse of favorable circumstances their origin and development is due, we need not be astonished at the relative rarity of such deposits in Cornwall.

VI.—*Influence of parallelism.*

a. Opposition *(vis-à-vis)*, of riches in lodes which are nearly parallel.

It is a well-known rule in mining countries that whenever a lode is rich for a certain extent, the branches or neighbouring lodes which are nearly parallel are likely to be "cut rich" by a cross-cut starting from the profitable region of the first lode, and in a direction at right angles to the common bearing of the lodes.

I will examine briefly the analogies of structure of parallel lodes in a given "country," and within what limits the rule of opposition of riches may be depended upon.

In each of the numerous mining districts of Cornwall the lodes are productive in lines which seem to be perpendicular to their respective directions, hence the expression "ore against ore." But as the directions of the lodes vary in the different districts, the directions of these productive lines are not always the same.†

In each district, by a coincidence which cannot be fortuitous, the productive lines are *oriented* almost like the principal cross-courses.* But the existence of the former is a fact superior to the latter; the enrichment that the lodes owe to the influence of a common cross-course increases the analogy of the position of their riches, but is itself due to the analogy of structure of the parallel veins.

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* The "exploitation" of this lode was very active. Trelawney began to sell ore in 1844, Mary Ann in 1846; from these dates to the latter months of 1868, or a mean period of 23½ years, the value of the mineral extracted reached the sum of £919,709. Wheal Mary Ann was stopped in 1874.

† Henwood Address, p. 11, and Met. Dep. p. 215.

Let us consider first the lateral branches of a lode, and then the case of two parallel lodes very near together.

In a lode, it is by the side of a normal rich part that one must expect to find parallel branches which are rich and of proper bearing; the miner is not ignorant of this, and does not commit the blunder of driving his cross-cuts from the parts which are poor and thin. Owing to the longitudinal extent of similar veins and rich branches being considerable compared with the space which separates them transversally, the opposition of riches subsists whatever may be the difference (a) of *orientation* of the veins and of the "country." If two lodes nearly parallel and not far apart, enclosed in rocks of which the strike is nearly the same as their bearing, and of which the inclination (i) is moderate, are projected upon a vertical and parallel plane, the result is a *partial superposition* of the projections of the rich bands.

A cross-cut driven at right angles, may, if it appears included in this zone of superposition in a vertical plane, tie together the two rich parts, while being driven entirely in the same favorable strata. If the two lodes are more distant, if they differ in direction of underlie, if the beds are more inclined, or thinner, the normal riches which are superposed in projection will be enclosed in distinct beds; the cross-cut, if well placed, which puts them in communication, will have had to cut through, horizontally, one or more bands of bad rock.

As the angle (a) increases, the superposition will happen more fortuitously; we leave the case of lodes proper and pass on to caunters. Now it is very evident that the rule of productive lines can only apply in each locality to a single group of principal lodes, *i.e.* to those whose *orientation* is pretty near to that of the containing rocks.*

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* "Parallel lodes are frequently productive on the lines of the principal cross-courses, or *ore*, as the miners say, is found *against ore* in different lodes; and they often yield much ore on both sides of a cross-course, or on one side only." R. W. Fox, *On Mineral Veins*, p. 88.

The expression "ore against ore" no doubt attained its general use in the anciently explored Gwennap district, and it is confirmed in the mines of Redruth, Illogan, and Camborne.

In these districts the angle a is small, and in some places nothing; the structure of the normal rich part is a "course of ore" very slightly inclined, sometimes appearing in a great curve following that of the hill; such were the great courses of ore in Consolidated Mines, referred to by Capt. R. Tregaskis, and Mr. R. W. Fox.†

In these districts the parallelism extends itself not only to the lodes and the killas, but also to the granitic hill and the numerous elvans. The *courses of ore* occur both as *normal,* and as *accessory* rich parts; subordinate to the elvans, changes of country, and even to the numerous and almost horizontal junctions.‡

The very inclined shoots are only connected with certain cross-courses, or with the intersections of or junctions with some other lodes, and particularly with some excellent caunters.

The Camborne and Illogan district§ presents at the present time the finest example of these phenomena of parallelism. Without entering here upon the study of its geological constitution, and of the important mines included therein, I will try to sketch the group of parallel lodes worked in about twenty mines, which may be divided in four groups—corresponding to as many successive zones, which border the north side of Carn Brea hill. The length of this little territory is about 2½ miles, and the breadth measured from S.S.E. to N.N.W. is nowhere more than 1½ miles. Plate VI, is a reduction to the scale of 1½″ to the mile (or $\frac{1}{41{,}907}$), of a part of a map drawn up by Mr. R. Symons in 1850; it also contains a section in a direction which is nearly N.N.W.

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* If we consider a group of cross-veins, the productive line will approach from the direction of the strata, and the rule of opposition of riches will again be evident. The beds of rock are cut through transversally by parallel lodes, and these sections being almost identical, it would be quite natural that a similarity should exist as to the configuration and the position of the riches in the cross-veins.

The lodes of the Liskeard district, up to this time worked in three different N. and S. zones, may some day have their parallels flanking them respectively, but this is not the case yet.

† See Chap. 1, p. 15, development of the third general character, *dip of the rich parts.*

‡ Mr. Charles Thomas, speaking of the great metalliferous zone which bears E.N.E. (E.W. mag.), says at page 7 of his "Remarks," "wherever in the direction the great beds of secondary granite (mine granite), compact clay-slate, greenstone, white granular killas, and elvan courses are found, there the great deposits of copper have been found."

§ After having been one of the regions most productive for copper, the district now contains the finest tin mines in Cornwall. It forms with the districts of Redruth and Gwennap a rectangle of about 15 square miles. The length measured in a direction E.N E., is about 6 miles, and the breadth about 2½. Within this area, which is smaller than many French mining setts, there has been raised copper ore alone to the value of 30 millions sterling. In 1859, the date of Mr. Chas. Thomas's memoir, the annual produce of copper was still half a million sterling, *i.e.* equal to the entire produce in copper of all the rest of the mines of Cornwall and Devon.

The granite island of Carn Brea is simply an outlier of the mass of Carn Menelez. The great masses of Cornwall, and especially that of Carn Menelez, appear on the map generally in a somewhat elliptical form. Their structure, owing to the intersection of the lines of upheaval and consequent fissures, is in reality that of irregular polygons. Still, it must not be lost sight of, that these granite bosses are the land marks of successive upheavals, and that they are really parts of complete granitic chains, so that *upon those flanks whose bearing corresponds with that of the principal chain, nothing interferes with the parallelism of the strata,* whilst upon the other sides the schistose covering is subject to local contortions. Two neighbouring bosses have between them a granite *col,* upon which the killas forms a *saddle.* These two bosses are connected by a subterranean ridge of the same rocks, which determines the anticline of the stratified rocks. Near the centre of one of these intervals between two neighbouring bosses, the bearing of the strata may be quite well defined, and their different beds quite regular, but as we approach the granite in either direction the curvature becomes evident. The central chain, the existence of which is indicated by the masses of Carn Menelez, St. Austell, and Bodmin, owes its elevation to the system of Westmoreland, bearing E. 40° 24′ N.; we have already noted some lines parallel to this system which are well characterized in this region of the peninsula.* But the direction of the system of Finistère† E. 21° 46′ N., is also strongly marked in the same district. The obtuse angle of 161° 22′ comprised between these two directions is the measure of the interior angle of the granitic polygon. We shall find it farther on in examining the groups of lodes, and it is readily recognizable in the form of the islet of Carn Brea.

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* Elie de Beaumont, *Systèmes de Montagnes*, pp. 181 and 193.

† *Ibid*, p. 331.

Let us suppose, finally, a vertical section bearing N. 31° W., this will pass from the granitic plateau to the little schistose valley in which the Basset Mines are opened, then through the granitic hill of Carn Brea, and, thanks to modern workings, we shall see again, under the covering of killas, the profile of the subterranean granitic ridges in the mines of Carn Brea and East Pool.

I owe to Mr. H. C. Salmon the following description of the four zones of mines.*

The first, proceeding from the granite from east to west, comprehends the mines of Carnbrea, Tincroft, part of East Pool, Cook's Kitchen, Dolcoath, Stray Park, and Camborne Vean. The outcrops of the principal lodes are in the killas, but all pass into the granite at a depth which is generally less than 110 fathoms below the adit; the first underground ridge occurs in this zone, and its highest points approach, in places, within 150 yards of the surface.

The second zone includes Wheal Tehidy, parts of Wheal Agar and East Pool, South Crofty and South Roskear: as yet the granite ridge has only been reached at East Pool.

The third zone is that of North Pool, part of Wheal Agar, North Crofty, and North Roskear.

The fourth comprises West Tolgus, East Seton, Wheal Seton, and West Seton.

Besides the principal lodes, there are in the four zones a number of Caunters bearing from W. 3° N. to W. 30° N; I may mention that of N. Roskear and S. Roskear, that of Dolcoath, and the great lode which, starting from the eastern side of N. Crofty, unites itself to the West Seton Lode, and which, having been worked under the name of Reeves' Lode at N. Crofty, has given under the name of the Great or North Caunter, at Wheal Seton, the magnificent course of Copper ore represented in Plate 1. fig. 1.

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* Min. Smel. Mag., vol. 1, p. 384. (1862.)

In Table XII the mines of these four zones are grouped in three columns nearly perpendicular to the course of the lodes.

TABLE XII.

Zones		← West			↑ North		East →
	4	West Seton, Wheal Seton			East Seton		West Tolgus
	3	North Roskear			North Crofty		North Pool Wheal Agar Wheal Tehidy
	2	South Roskear			South Crofty		
	1	Camborne Vean	Stray-Park	Dolcoath	Cooks' Kitchen	Tincroft	East Pool Carnbrea

The above table gives in each vertical column the mines which occur opposite to each other (*vis-à-vis*); but on referring to the map we see that the three columns diverge from each other like a fan in receding from the granite. Thus, in drawing by way of comparison, lines such as A.B.C. bearing N. 31° 5′ W, we observe that they are parallel to the bisectrix of the obtuse angle 161° 22′ already mentioned. The line in question passes to Carnarthen in A, cuts through the rugged summit of the granite mass, and at the point B. approaches the northern limit of the narrow sett of Cook's Kitchen. From B to C it almost exactly separates the western from the central column. Parallels to the systems of Westmoreland and Finistère respectively, through A, westward in the direction 40° 24′ south and eastward 21° 46′ north, enclose the two extreme points of the granite islet; if similar lines are taken 330 yards more to the north they pass through the culminating points of Camborne Beacon to the west, and Carnbrea Monument to the east.

Through B one line has a mean direction which is nearly that of a part of the great lodes of Dolcoath, Stray Park, &c., (and, if prolonged, passes to Pendarves and St. Aubyn Consols Mines); while the other corresponds with a part of the lodes of Tincroft and Carnbrea.

Through C, a point arbitrarily chosen, the lines go on the left to West Seton, and on the right to West Tolgus.

The perpendicular to the system of Finistère is N. 21° 46′ W. and it differs very little from that of Forez which is N. 23° 22′ W., and from the much more ancient system of Vendée which is N. 26° 13′ west. The cross-courses attributable to the system of Forez, therefore, naturally predominate in this region; near to this direction N.N.W. we see in the western column many cross-courses which bear nearly N. 40° W., *i.e.* tending towards the perpendicular of the lodes, whilst at the extreme east of the map some cross-courses bear nearly N. 8° W. like the system of the North of England, or the perpendicular to the Land's End.

According to Mr Henwood the general mean bearing of the cross-courses of this district is N. 34° W. which differs but little from the bisectrix N. 31° 5 W. of the obtuse angle Finistère—Westmoreland; the principal lodes vary from E. 20° N. to E. 40° N.[*] and these limits coincide practically with the respective directions of the two systems mentioned.

At the epoch when the action of the Westmoreland system ceased, what was the direction of the E.W. fissures, fractures, or openings in this district? Those due to the system of Finistère must have been pretty straight, and in the two groups F*c* (underlying South) and F*a* (underlying North) the mean directions would diverge but little.

The fractures attributable to the Westmoreland system would, on the contrary, diverge some degrees, those of the type F*a* tending in the direction of the beds, *i.e.* E.N.E., those F*c* towards the N.E.

Even at that period a certain number of fractures, no doubt, presented considerable inflexions (18° 38')[†] *i.e.* they were made up of elements taken from both systems.

Finally, some fissures, due to the system of Morbihan, W. 36° 13′ N. might have cut through the strata, but their numbers would be much less here than in other districts. During the Devonian period[‡] the system of the Land's End, E. 8° 23′ N., the influence of which predominated in the east of Cornwall and

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[*] Met. Dep. 1843, p. 64, 65. "The principal lodes of this district have a bearing which varies from 20° to 40° S. of E., but some of them dip to the N., and others to the S. There are many *Caunter-Lodes* varying from 10° to 30° N. of W. but they have almost exclusively yielded copper ore."

[†] See for their bearings and the relative angular values of the eleven ancient Systems, the table in Note D.

[‡] Mr. S. R. Pattison in the *Annual Report of the Royal Geological Society of Cornwall*, 1852, has summarised the Geological Classification of the ancient rocks of Cornwall to that date; he thus defines the Devonian series.

II. Devonian (or middle Palaeozoic)	1. Upper	=	Petherwyn Group A.
	2. Lower	*a*	Plymouth Rocks B.
		b	Liskeard Group C.

Devon, acted very effectively upon the rocks of the west, which were already fissured by the systems of Finistère and Westmoreland; the acute angles so produced between Land's End and Finistère, and Land's End and Westmoreland, being only 13° 23′ and 32° 1′, the movements of the ground became transmitted to the openings already existing, and thus a relatively small number of great new openings were produced.

The system of Ballons, W. 5° N. (belonging to the carboniferous period) having a greater divergence, produced a series of caunter lodes and also re-opened many fissures belonging to the systems of Land's End and Finistère, and even certain fissures due to the Morbihan system. The angles between the Ballons system and those of Finistère, Westmoreland, and Land's End, are 26° 46′, 45° 24′, and 13° 23′ respectively. Thus, as might be expected, the Ballons fissures in this district often became chiefly visible as in the east and central columns of Table XII, *i.e.* in the neighbourhood of the lodes of the Westmoreland system. Of these caunters the lodes F*a* tend to approach each other in going west, and the lodes F*c* in going W.N.W.; all are apt to form junctions and lose themselves in the E.W. veins already existing.

Among the caunters, I have already mentioned the fine lode known as *Reeve's** whose bearing is W. 3° N., and which dips northward about 73°; I have also mentioned the caunters of Dolcoath, North Roskear, and South Roskear, which are very rich, but less explored in length; all these dip southward like the principal lodes with which they form junctions.

The system of Forez and that of the North of England, acted during the deposit of the millstone grit and the coal measures, interrupting the series of east and west movements commenced by the system of Westmoreland, and continued by those of Land's End and Ballons. But the system of Pays Bas, E. 14° 55′ N. almost exactly bisecting the bearings of Finistère and Land's End, exercised at a later period a most efficaceous action in reopening the east and west fissures, and bringing into play the great masses cut through by the cross-courses.

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* Mr. H. C. SALMON (*Min. and Smelt. Mag.*, vol. ii, pp. 74 and 277), gives a very interesting description of this lode, which has been followed with advantage in North Crofty, part of North Roskear, and Wheal Seton, and in which workings are opened for a length of nearly a mile. The eastern portion, that of N. Crofty, measures 3-5ths of a mile; a cross-course divides this sett from the northern angle of North Roskear which the lode then crosses for a distance of about 180 fathoms, after which it enters Wheal Seton, where it is known as the *great* or *north caunter*, and is heaved to the right from 20 to 25 fathoms. Fig. 1, plate 1, represents the workings in these two latter mines. After a course of nearly 130 fathoms in Wheal Seton, the lode turns rapidly towards the west, so that within a space of about 40 fathoms, its direction is changed no less than 36°; from here the lode, which should, I believe, be regarded as absorbed by another vein, traverses West Seton, and still going westward, reaches New Seton. The new mean direction is E. 33° to 34° N., or almost exactly that of the "right-running" lodes of the district,

The presence of silver ores at certain points in some of the lodes is a certain indication of other systems of disturbance of less ancient date in this region, but all the principal fissures existed at the close of palæozoic times.

Before summarising the preceding facts as to the parallelism of lodes, we may note from Mr. Henwood, that, in Cornwall, "although levels have often been driven in adjoining mines for considerable distances on the course of a given lode, it is not certain any one lode has been really traced for more than a mile."*

The separation of lodes into different "setts" materially increases the difficulties of observation upon the continuity and identity of lodes, but the uncertainty referred to by Mr. Henwood is due to more general natural causes.

Reverting to hypothesis, we may suppose that in strata such as those with which we are concerned, but free from great pre-existing dislocations, there will be produced under the influence of a single system of upheaval, certain east and west fissures of both kinds (F*c* F*a*) cutting through the schists at a little distance from the granite. The schists are moderately inclined, they present a general curvature towards the north, and their beds are distinctly convex.

We will select in this region two fissures, one F*a*, the other F*c* (dipping north and south respectively) which have a proper bearing tangential to the curve of the strata, and follow these both eastward and westward.

Necessarily, the angle a will increase on either hand, whilst the deviations (x—a) in passing through the bad beds are themselves augmented. The fracture F*a* will therefore form a great arc, of which the convexity, although less than that of the strata, will be turned in the same direction, *i.e.* towards the north, whilst the fissure F*c* will give an arc of inverse curvature. But as the angle a increases, and supposing that the strata remain of the same nature and that the mean dip is constant, we have seen that the *cannelures* if not effaced, at least lose much of their distinctness. Let us suppose that later on, certain movements of the ground having a little different bearing to that of the system of fracture, have determined a descent of the hanging wall. The amount of fall will no doubt differ at different points, but with an equal amount of fall the separation of the walls destined to form channels for the normal riches will become less and less, because it will occur in a part of the lode where the mean direction is more inflected; the narrowing of the opening will be a consequence of its inflexion.

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* It is generally believed however, in Cornwall, that the same lodes in Gwennap and elsewhere, have been worked upon at different points several miles apart, and that the main cross-courses have a greater longitudinal extent than the lodes; some of these are known to extend completely across the county.—J. H. C.

But if phenomena of this kind have had some influence in the Camborne district, some other more direct effects of the systems of fracture have produced there a complexity in the deposits. Not to speak of the uncertainty which may have been introduced by the north and south cross-veins, the complex results of the five east and west systems, Finistère, Westmoreland, Land's End, Ballons, and Pays Bas, are sufficient in this district to account for the doubt expressed by Mr. Henwood, as to the possible length of a single lode.

The two first systems furnished the essential characters which the three following ones connected together and developed. The deviations, the still greater inflexions, and the apparent curve of certain lodes at the foot of the granitic hill, form together a natural mass of numerous intersections, sometimes slightly undulating, sometimes nearly straight, at other times interrupted, at others again crossing each other, so as to resemble a drawing in which the shading is indicated by different sets of cross-hatchings; but always connecting themselves with the two directions which are here fundamental; those of Finistère and Westmoreland. These, both eastward and westward, indicate by their perpendiculars the productive lines. This parallelism does not exist equally in all the mining districts of Cornwall, but as a whole phenomenon it results from this that the E.N.E. bearing predominating in the rocks is found also in the principal veins.

The tradition of the miner upon this point, as upon many others, is solidly based, and we say with him that if it is good sometimes to explore the prolongations of a lode known to be rich, it may often be still better to work *parallel lodes opposite to the rich points of lodes already known.*

CONCLUSION.

I have sought to shew by what intimate relations the general conditions of a lode are connected with those of its enclosing rock, what practical advantage there is in knowing the strike of the rocks, and the direction of the system of fracture, and where and how the miner should observe the latter.

A properly prepared fissure is the indispensable prelude to a good opening, such as, *the opportunity occurring*, would be able to contain good "normal" riches. But, if by different mechanical phenomena, the subterranean channels have been multiplied in the lode and its immediate neighbourhood, these special openings will have constituted proper receptacles for abundant accessory riches.

These conditions being satisfied, there are yet others which have aided in the formation of metalliferous deposits, and from a mechanical point of view in order that such deposits should be formed, it was necessary that, at the geological period when the productive fluids were circulating in their natural conduits, the movements of the ground should be in such directions as to facilitate the opening of fissures and fractures, or the re-opening of pre-existing lodes and fissures.

A knowledge of the "circle of directions," (*rose des directions*) which M. Elie de Beaumont so justly called "a resumé of geological phenomena," serves in studying the strike of the strata, to mark precisely the bearing of the System of initial fracture, enables us to follow the complex movements which have prepared places of deposit for accessory riches, and finally, to determine at what geological epoch, *i.e.* under the influence of what System of upheaval, such metalliferous fluids have been poured out in one or more districts.

An example will enable us better to appreciate how in setting out from the elementary ideas exhibited in the present work, we may approach the study of the principal groups of lodes in Cornwall.

During the formation of the permian rocks, numerous great deposits of copper were produced in many countries of Europe. There is, *a priori*, reason to believe, that the rich copper mines of Devon and Cornwall have participated in this considerable afflux of mineral wealth.

The permian formation has for its base in Devon a series of arenaceous beds, which occupy the region north of Exeter;* certain movements of the ground brought the south of the county at that epoch in communication with the northern basin, and deposited a series of conglomerates over a large extent of country. We may connect these movements with the system of upheaval of Pays Bas or Hainault, the bearing of which in Cornwall is about E. 15° N.*

They are also distinguishable in the ancient rocks to the west and south west of Exeter, which had been previously fissured by the older systems.

What then would be in each district the fissures, openings, or lodes most likely to open or re-open so as to receive the cupriferous waters and to retain the deposits of copper?

The system of Pays Bas forms new fractures; those of Land's End and Finistère will form with it the very acute angles of 6° 32′ and 6° 51′; with the direction of Ballons the angle will be only 19° 55′; with that of Westmoreland 25° 29′. We may evidently, therefore, expect to find that the fissures, openings, or lodes whose bearing is nearest to that of the system in action, will rather than others be opened or re-opened by the descent of their hanging walls; in the meantime, by the movement of portions of country differently fissured, many other groups of veins over a more or less limited extent will be benefitted by the movement of the ground, in spite of their divergence from the system of Pays Bas.

Going westward, we find below the carboniferous schists the Devonian formation, which extends downward to the lower schists of the neighbourhood of Liskeard; here the direction of Land's End predominates, that of Ballons, which only differs by 13° 23′, is observable in places, whilst the more ancient east and west systems are very indistinct.

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* De la Beche; Report on the Geology of Cornwall, &c., pp. 199 and 215.

* The bearing of the great circle Da—carried to the point $a^{iv.}$ is E. 14° 54′ 52″ ·16 N.

On the contrary, we have seen that in the west-central part of Cornwall the best districts bear the direct impress of the systems of Finistère and Westmoreland, and traces of those of the Land's End and Ballons.

If from great divisions we turn to the different parts of one single district, we shall have to state some new differential characters as regards both the normal and the accessory riches. In fact as the composition, inclination, and bearing of the rocks vary generally in different districts, *the characters* (allures) *of the openings due to the same system of fracture are not the same.*

If one of these elements, and especially the strike of the rocks, should differ sensibly, it will be sufficient to cause the opening to take in one place the character of a *course of ore*, in another, an inclined *shoot;* in one place to be a principal lode, in another, a caunter lode.

As to the accessory riches, the qualities and relative characters of rocks of different nature, killas, granite, or elvan, which enclose a single vein, will introduce in each district very unequal results. Junctions and intersections will occasion a still greater variety, for not only does each district possess in unequal degrees fissures due to several systems, but, moreover, the fissures of common origin not having exactly the same surroundings, the movements of portions of rocks which they cut through have been different.

All these variations will come to be appreciated when they are connected with their essential causes; very numerous are the phenomena, and very various their results, but miners are attentive and persevering observers.

Even now, if the mining engineers of Cornwall see their own interest, it is easy for them to determine by personal observation the *good direction* of each of their lodes. I believe that they will soon make use of the numbers calculated for their county, but if without regarding these numbers they observe with attention the bearing of each lode in its normal rich parts, they will soon ascertain by comparison the practical exactness of the calculated directions.

The example and advice of Mr. Henwood* must be followed; "Obtain more experience, compare facts with greater care," and the miner must profit by the progress of geology, and give to the art of mining a scientific basis.

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* "A more extended experience, and a more careful array of facts seem our only resource," *Address*, p. 20.

M. Elie de Beaumont well said, "Thus a growing science will be born where there will be much less of mystery; a science partly new and almost completely experimental, of which the introduction in the mines will before long become a question of public utility."*

No mining country is perhaps better suited for the development of such studies than Cornwall; the field of exploration, without being too great, is as rich as it is varied, while there is also a unity of interests, a number of eminent scientific observers, and a body of able and energetic practical men.

Our age has produced worthy successors to Pryce and Borlase. The Royal Geological Society of Cornwall may well boast the names of Dr. Boase, J. Carne and W. J. Henwood; the Royal Cornwall Polytechnic Society those of R. W. Fox and Robert Hunt.

The Miners' Association of Cornwall and Devon, which forms a permanent link between the scientific observer and the practical miner, was originated by Mr. Hunt in 1859, and its affairs were conducted by him until failing health compelled him to resign the position of Honorary Secretary in 1871.

As such influences come into operation, we may expect that before many years have elapsed there will be much less uncertainty than at present. In proportion as the miner penetrates into the depths of some of the inexhaustible districts of Cornwall, he will approach with confidence the technical problems upon which he merely touches to-day; for, to increasing material difficulties he will oppose the knowledge of the *allures* of the mineral riches, which each day renders more complete.

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* *Progrès de la stratigraphie en France* (1869), p. 559.

APPENDIX.

NOTE A.

Explanation of certain terms used in this work, with the meaning which is given to them in the theories of M. Elie de Beaumont.

THE theories of M. Elie de Beaumont have reference to two successive and distinct orders of phenomena. The first relates to the relative ages of mountains, and to their grouping into contemporary and parallel chains; the second is a correlation of the directions of the different Systems by means of a *pentagonal network*, or figure representing the geometric law according to which the positions of the different Systems are connected with each other.

There is no intention to give, in the few pages available for this note, even a short explanation of those great labours which were commenced in 1829, and continued during 40 years. The object of this note, which is specially written for the English Translation, is merely to summarize some of the principal features of the doctrines of M. Elie de Beaumont, so as to enable those readers of this work who may be unacquainted with them, to understand the sense in which such expressions as Direction of a System of Fracture, Mountain System, Stratigraphic System, Great Circle of a System, point (a^{IV}) &c. are used.

The author is well aware of the difficulty of giving to such a resumé, the necessary amount of clearness; in making the attempt, he wishes at once to comply with the expressed desire of his distinguished translator Mr. J. H. Collins, and with the recommendation of his venerated master, M. Elie de Beaumont, made in July, 1874, when he heard of the proposal of the Council of the Miners' Association to issue a translation of this work.

1.—*Mountain Systems.*[*]

Definitions.—"Fractures effected in the exterior crust of the earth have determined the elevation and uptilting of the rocks of which this crust is composed, and the crests of these broken and upturned beds of rocks form the summits of those asperities of the surface of the globe which we call mountain chains.[†]

"Mountain chains are either *straight* or made up of straight 'elements,' to which we may give the name of *links.*"[‡]

"The different "links" observable over a large extent of country, though presenting great variety of direction, are mostly connected with a limited number of *orientations*. Each group of mountain links or *topographic accidents* characterised by frequent repetitions of one of these *orientations*, is what we call a Mountain System.[§]

We may then regard the expressions 'mean direction of a System of fracture, mean direction of a System of upheaval, and direction of a Mountain System,' as almost synonymous. The meaning of the term *System of furrowing* is wider, because it includes the larger undulations of the drainage system as well as the mountains themselves, but the expression Mountain System is generally preferred, because it relates more especially to the best characterised portions of the System.[||]

In 1829, in his first memoir, M. Elie de Beaumont only treated of 4 European Mountain Systems, but soon after he indicated 21. In 1869,[¶] he announced that in consequence of the labors of different geologists in all parts of the world, 85 Mountain Systems were already pretty well defined, and he thought that within a few years the number would be at least 100.

Relative Age.—The parallel links which constitute a Mountain System are contemporaneous; we are able to determine the relative ages of different systems by a consideration of the following facts.

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[*] See *Notice sur les Systèmes de Montagnes, par L. Elie de Beaumont*, 3 vols., 8vo. Paris, published by P. Bertrand, 1852. Most of the definitions here given are taken from this work.

[†] *Syst. de M.*, p. 11.

[‡] *Syst. de Mont.*, p. 2.

[§] *Ibid.*

[||] *Ibid*, p. 11 and p. 1316.

[¶] See *Rapport sur les Progrès de la Stratigraphie en France, par L. Elie de Beaumont*, 4to. Paris, Imprimerie impériale, librairie Hachette, 1869.

In each mountain range, or at least in each group of parallel links, the sedimentary beds may be divided into two classes.* The more recent beds are horizontal right up to the flanks of the mountains; the others, on the contrary, are upheaved and rest upon those flanks; and sometimes are even elevated to form their crests. It is evident that the elevation of the chain or group of parallel links took place at a date between the periods when the two classes of beds were deposited. The two classes of beds correspond also with distinct formations in the general series of stratified rocks.

The age of a Mountain System may then be determined by observing the unconformability of strata whose geologic ages are known, and it is found to be very clearly determined whenever such unconformability shews itself in a series of sedimentary rocks.

Parallelism upon the earth's surface.—In studying these furrows and fissures in the earth's crust which have been produced at any particular epoch, if our observations are confined to a country of small extent, the curvature of the earth is scarcely sensible, so that we are able to apply the idea of parallelism without difficulty to the different natural irregularities which may exist in any one System.†

But when we extend our observations over regions of great extent, it is necessary to define what is meant by parallelism at the surface of a sphere. "If we draw any straight line on the surface of the earth, either by a line of stakes, or in any other manner, if we disregard the effects of refraction, and that due to the spheroidal form of the earth, such a line is always an arc of a great circle."‡

In general, any two arcs of great circles, even when not *very* short, may be said to be parallel to each other, if they are so situated that they may be both bisected at right angles by a third great circle†.

Thus, the short arcs of great circles A B and C D, fig. 1, plate VIII, may be regarded as parallel, being cut at M and M′ by a great circle EF, forming with them the right angles M and M′.

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* *Syst. de Mont.*, pp. 5, 6.

† *Syst. de Mont.*, p. 16, et seq.

‡ *Ibid.* p. 17. † Ditto.

These arcs AB, CD, may be regarded as little arcs of meridian, situated near to each other, and cut by the equator EF.

A series of *links* are parallel (by our definition) when we are able to draw a *great circle of comparison,* such that arcs of great circles drawn through central points of the respective links perpendicular to their direction, are also perpendicular to the circle of comparison. Thus, the chains CD, EF, GH (fig. 2) are parallel, because the arcs of great circles IK, LM, NR, are all perpendicular to the great circle of comparison AB.

Determination of the provisional great circle of comparison of a Mountain System.—"The fundamental problem, which is presented by a system of short parallel arcs observed upon the surface of the globe, as indicated by the crests of mountains, or by the upturned edges of stratified rocks, consists in determining a *great circle of comparison* such that each of the little observed arcs is parallel to some corresponding element of the said great circle.* The condition of parallelism is only in general approximately satisfied, so that we should rely only upon great numbers of observations over a great extent of country. In combining these observations we are able by successive approximations to determine at least a provisional great circle of comparison for the system; *i.e.* we may choose the direction and mean position of the circle, and fix it by giving the geographical co-ordinates of a point O of the circle, and the angle a, which its direction makes at this point, with the meridian OP (fig. 2).

We may also fix the position of the circle by calculating two quantities which enter very frequently into other calculations. For this purpose we note the point M (fig. 3), where the circle cuts the terrestrial equator, and the point A situated at 90° from M upon the great circle. In A the circle being cut at right angles to the meridian PAN, we determine the longitude of L (=OPN) and the co-latitude b (=PA) of the point A. The great circle is thus fixed.

M. Elie de Beaumont in his *Notice sur les Systèmes de Montagnes,* has studied 21 systems in western Europe, has defined their great circles of comparison (retaining for their circles the term *provisional*), and has given to each system a geographical name, taken from some locality where its existence has been recognised. He has also followed up the study of some of these systems in other parts of the world. Among these 21 systems the most ancient is the System of la Vendée, whose bearing in Vendée and Brittany is N.N.W.; the most recent is that of Ténare, Etna, and Vesuvius, the bearing at Etna being N. 8° 20′ 43″ W.

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* Ibid, pp. 19, 20,

Extent.—It appears from his observations, that a Mountain System is seldom more than 10° on one side or the other of its great circle of comparison. It is seldom that the movement has been prolonged, so as to produce a complete circle, or even half a circle. It appears as if the existing fractures of the earth's crust have served in part instead of new ones, and that new fissures have sometimes been produced so as to prolong those already existing.

Finally, as the greatest amount of surface occupied by a Mountain System is never more than $\frac{1}{18}$ ($= \frac{20}{360}$) of the surface of the globe, no disturbance of stratification is universal.

Transport of the direction of a Mountain System to any given point. When we study in any country of moderate extent, the directions of the upheavals to which stratified rocks have been subjected, and desire to recognise those which are connected with certain Mountain Systems, we choose a point as central as convenient through which we draw parallels to the great circles of comparison. Knowing then the *orientation* at the point chosen (M), *i.e.* the angle which each direction makes with the meridian, we may regard this orientation as constant in the district, for the error thus made will be less than that which necessarily attends practical observations on directions.

For each System, the operation consists in taking from the point M (fig. 4) fixed by its geographical co-ordinates, an arc of a great circle MC perpendicular to the great circle of comparison AB of the System. The angle BMC formed at M by the arc MC with the meridian PMB of the place, is the complement of the angle sought, PMX, which is made in M with the same meridian, by the direction MX parallel (by definition) to the System.

As to the trigonometric calculation, it consists in a resolution of the two rectangular spherical triangles if the great circle has been determined by the quantities L and B indicated above.

Let L′ be the longitude and l′ the latitude of the point **M** (fig. 4), we consider successively the triangles PAB and MCB.

In the first the angle P=L+L′ and the side PA=b are known, from which we may calculate the angle PBA and the hypotenuse PB.

Again, knowing PB, and the co-latitude PM=90°—l′ of the point M, we have in the second triangle the angle B and its hypotenuse MB=PB—PM, whence is calculated the angle BMC. The *orientation* of the System transported to **M** is PMX=90°—BMC.

In the same triangle, the calculation of the side MC, which is a perpendicular dropped from the point M upon the great circle of comparison, determines at what distance the great circle passes this point. As already mentioned MC should not exceed 10°.

M. Elie de Beaumont, besides having determined provisional great circles of comparison for 21 Mountain Systems, has transported their directions to three points in Europe, *viz*:—to Milford in S. Wales, Binger Loch on the Rhine, and to Corinth.

2.—*The Pentagonal Network.*

Having separately studied 21 Mountain Systems occurring in Western Europe, and fixed their provisional circles of comparison, M. Elie de Beaumont investigated the mutual relations of these 21 Circles. He especially calculated the 210 angles made by these circles in taking them in pairs. "These angles form, in the space of a quarter circle, *a series of groups, separated by tolerably wide spaces.*[*]

Observing this grouping, which could hardly be the result of chance, it occurred to him that he had under his eyes the indications of a law of correlation of the positions of the great circles of comparison, and that if the circles were not placed by chance upon the surface of the globe, they must necessarily form part of a *network* subject to some *principle of symmetry*.[†]

He endeavoured, at first, to devise a system of projections in relation to three planes crossing each other at right angles, as in the

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[*] Syst. de. Mont. p. 877.

[†] See *Revue des Cours Scientifiques*, 6e *Année* No. 24, 15th May. 1869, *Le Réseau Pentagonal* p. 370 to 381; an article extracted by M. Elie de Beaumont from his *Rapport sur les progrès de la Stratigraphie en France*,

"regular system" of Crystallography. But, having calculated a great number of angles in the net-work thus formed, he observed that those points in the quadrant, which were thus naturally associated together, had no connection with those which were determined from the angles deduced from observation. He was, therefore led to give up this first attempt.†

Instead of this quadrilateral network derived from three rectangular planes so cutting the sphere as to form 8 equilateral triangles, he endeavoured, and this time with success, to form a network composed of 20 equal equilateral triangles, having angles of 72° and sides of 63° 26′ 5″·84, so as to include the whole surface of the sphere. The sides of these 20 *equal equilateral triangles* formed parts of 15 *primitive great circles*, which divided the surface of the sphere into 12 regular spherical pentagons, having angles of 120°, from which the designation *Pentagonal Network* has arisen.

Short Description.—We can only give here a few mere indications of the constitution of this remarkable figure.

Around the point D (fig. 5, plate VIII) the circle of 360° may be divided by radii into 5 angles of 72°; the prolongation of each radius to the other side of the centre divides the opposite angles into two angles of 36°. There are, upon the sphere, 12 such points D, forming the centres of the pentagons fig. 10, and 20 points I forming summits of 20 equilateral triangles.

In the centre I of each triangle DDD, (fig 6) the circles intersect at angles of 60° or 120°. There are 20 such points I, and, further, the circles are cut at right angles in the points H, in the bisections of the sides of the 20 triangles—consequently there are 30 points H.

The equilateral triangle DDD is divided by the apotheme D.I.H into 6 equal rectangular scalene triangles. The angles of these triangles D I H (fig 7) are respectively 90°, 60°, and 36°.

Two contiguous triangles DDD (fig 8) form a great rhomb of which the centre is a point H, situated at the rectangular intersections. Combining the arcs which join the centre I of the pairs of contiguous triangles, we form the pentagon whose centre is at D, which includes 10 scalene triangles.

Finally, we see that the smaller rhomb, whose centre is at H, and of which the diagonals are II and DD (fig. 8) is formed of 4 scalene triangles.

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† *Revue Scientifique loc. cit.* p. 371.

We see then that the 120 rectangular scalene triangles which include the whole surface of the sphere may be grouped in the following ways:—

12 Pentagons, each formed of 10 triangles, which are joined at the points D where these angles are 36° .... (12 × 10=120)
20 Triangles, each formed of 6 triangles joined at the points I, where these angles are 60° .... (20 × 6=120)
30 Rhombs, each formed of 4 triangles joined at the points H, where their angles are 90° (30 × 4=120)

The lengths of some of the lines of the network* may be set down as follows:—

Triangles D_1 D .	°	'	"
Side DD_2=	63	26	5·84
Apotheme DH_2=	58	16	57·08

Scalene Triangles DHI.	°	'	"
½ side DD_2=long side DH—	31	43	2·92
DI=hypotenuse DI ... —	37	22	38·50
IH_2=short side IH...... —	20	54	18·58
Perimeter.........	90 00	00	00

The figures thus formed by the 15 primitive great circles correspond to many regular solids. But for the object of the present note it is not necessary to work out the intimate relations which exist between the great circles of the *réseau* and the series of regular polyhedrons inscribed within or circumscribed around the sphere; it will suffice to say that the designations adopted by M. Elie de Beaumont for each group of derived circles of the first figure described, are taken from those different solids.

Fig. 10, plate VIII, represents one of the 12 pentagons. The great circles are represented as straight lines, owing to the (gnomonic) mode of projection which is adopted.† The four following groups of principal circles may be distinguished and represented by their *poles* upon the sphere (as in crystallography) viz.:—

6	regular dodecahedral	of which	the poles	are the	12	points	D
10	octahedral	,,	,,	,,	20	,,	I
15	primitive	,,	,,	,,	30	,,	H
30	rhomboidal dodecahedral	,,		,,	60	,,	T

In all 61 principal great circles.

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* Fig. 9 Pl. VIII.

† *i.e.* a projection by radii to tangent planes as planes of projection.

We see in the pentagon (fig. 10) five points T, which cut at the same time two octahedral and one primitive great circle, and which form the points of a little pentagon concentric with the large one.

The points already enumerated, viz.:—12 D, 20 I, 30 H, and 60 T, are called principal points of the *first order*, they amount in all to 122.

The rectangular intersections of the 61 primitive great circles afford three new series of points, called principal points of the *second order;* these are

60 points *a*	situated in the middle of the sides of the little pentagons of the points T, where the *octahedral* great circles cut the *primitive* at right angles.
60 points *b*	where the *regular dodecahedral* cut the *primitive* at right angles.
120 points *c*	where the *rhomboidal dodecahedral* cut the *octahedral* at right angles.

There are thus in all 240 principal points of the second order These points are the poles of three new series of circles, thus:

30 which bisect (IH) the angles I (60°) of which the poles are the 60 points *a*.

30 which bisect (DH) the angles D (36°) of which the poles are the 60 points *b*.

60 Trapezoidal (TI) of which the poles are the 120 points *c*.

The two groups of bisecting circles constitute a total of 60 principal circles of second order, whilst the 60 *trapezoidal* circles are called *auxiliary*.

M Elie de Beaumont has further shown how we may trace still other series, each comprising 60 auxiliary circles derived from the law of *Pentagonal Symmetry*, which are, however, subject to less strict conditions than the principal circles.

Summarising the preceding observations, we find the *réseau*[*] includes essentially—

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[*] See *Comptes rendus de l'Académie*, the following memoirs by M. Elie de Beaumont. T. LVII, 20 July 1863, *Tableau des données numériques qui fixent* 159 *cercles du Réseau pentagonal*. These are the 121 principal circles and 38 auxiliary circles belonging to several different series of 60 circles. T. LVIII, 15, 22, and 29, Feb. 1864. *Tableau des données numériques qui fixent les* 362 *points principaux du Réseau pentagonal.*

See also *Bulletin de la Société géologique de France*, 1st April, 1875. *Sur le Réseau pentagonal par* M. B. de Chancourtois (with a large plate).

Principal circles	61
Principal circles of second order	60
Total	121
Principal points	122
Principal points of second order	240
Total	362

Localization of the "réseau" on the surface of the Globe.—M. Elie de Beaumont was led by studying the *réseau* to calculate a great number of angles formed by the mutual intersections of the circles, and the accumulation of angular values brought out more and more their tendency to group themselves around certain points of the quadrant, differing but little from those groups already formed by the provisional great circles of comparison of the Mountain Systems of western Europe, established by observation.* The pentagonal symmetry might then very probably allow us to establish a correlation between the relative directions of the Mountain Systems, considered as forming a whole, of which the different parts successively produced are yet intimately connected together.† "But a decisive step still remained to be done, it was to point out among the principal or auxiliary circles of the Pentagonal *réseau*, that which belonged to each Mountain System."‡

M. Elie de Beaumont adopted a somewhat mechanical course of procedure. He placed on a terrestrial globe 50 centimetres in diameter, a moveable network of silk thread, consisting of twenty-five meshes, each having the form of an equilateral triangle, so that the sides of these triangles formed parts of 15 primitive great circles; he then added portions of some of the principal circles, and also of some of the auxiliary circles.

After repeated trials, he fixed the net in such a way that one point T coincided with Etna, the centre D of a pentagon fell near the middle of Germany, and the primitive great circle which passed through Etna, also passed through Mauna Roa, in the Sandwich Islands.

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* *Progres de la Str.*, p. 54. † Ibid., p. 32.

‡ See *Prog. de la Strat.* p. 58, and *Compt. rend.* T. xxxi. 9 Sep., 1850.

The following conditions accurately fix the position of the net; the centre D of the European pentagon is situated in

Latitude .. 50° 46′ 3″·08 N.
Longitude.. 8° 53′ 31″·08 of Paris.

At this point the *orientation* of the primitive circle passing through Etna is N 13° 9′ 41″·03 W.*

If we consider fig. 10 as representing the European pentagon, the point T″ being Etna, the point D is near Remda in the middle of Germany; and the point a^{IV}, the rectangular intersection of a primitive by an octahedral great circle, is situated near the western extremity of Cornwall.†

Returning then to his study of Mountain Systems M. Elie de Beaumont succeeded in finding for each System a great circle in the network which replaced the provisional great circle of comparison deduced from observation, and which then became the great circle of comparison of the Mountain System.

"The provisional great circle of comparison"‡ said he "has only been conceived as an *abstract line*, intended to represent observation approximately. The great circles of the pentagonal network are other *abstract lines* which may conveniently replace the former, but the great circles of the network which are realized in geological phenomena are especially noteworthy, as they coincide with certain physical lines with remarkable precision."

Stratigraphic Systems.—"Mountain Systems are the fundamental characteristics of the exterior configuration of the globe, and Stratigraphic Systems are the expression of its interior structure."§

The Term "Stratigraphic System" has a meaning which is both general and special. It includes the great foldings of the earth's crust, mountain crests, upheavals, inclinations and plications of the beds, and fractures of different kinds which have been produced at the same epoch under the influence of rectilinear movements acting in a direction parallel to the direction of a System, and this direction is fixed with geometrical precision by a knowledge of the great circle of the network which represents the great circle of comparison of the System.

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* *Prog. d. l. Strat., p*, 59, *Compt. rend.* t. xxxiii, Aug. 11, 1851, and *Syst. d. Mont.* p. 1028.

† See, for the exact position of the point a^{IV} the note to Table I in note D.

‡ *Prog. d. l. Strat.*, pp. 493-4.

§ *Prog. d. l. Strat.*, p. 1.

We cannot better complete the sense which M. Elie de Beaumont has attached to the epithet *Stratigraphic* than by concluding this note with the definition which he has given of *Stratigraphy* in the beginning of his last work.

"*Stratigraphy* is that part of geology which is occupied with the geometric description, and the graphic representative of mineral masses. These masses very often have the form of beds, (*strata,*) a word of which we have generalized the sense in the word stratigraphic.

Stratigraphy includes all that is susceptible of precise definition in the forms and adjustment of the mineral masses of which the crust of the earth is composed. It is the sister of geography, and it contains the quintessence of topography. It includes the great orographic features which the most celebrated travellers have illustrated, and it extends to the extreme ramifications of the metalliferous deposits observable in mines by the aid of the lamp and the compass."

Paris, April 21, 1877. L. MOISSENET.

NOTE B.

A resisting bed being broken at right angles, to calculate the bearing (x) and the dip (Pm) of the fracture in terms of the inclination of the beds (i), and of the angle (a) contained between their direction and that of the System of Fracture.

IN accordance with the above enunciation, we deal with a simple geometrical problem; introducing into the formulæ certain numerical conditions of which the values are indicated and limited by natural phenomena, we derive useful results for the study of the direction and dip of the poor parts in the lodes (F*c*) of Cornwall.

1st.—We consider two superposed beds; of which the upper is very hard, the lower of moderate hardness. In the latter, the fracture is *vertical* by hypothesis; whilst in the former, the fissure deviates according to a plane which is normal to the bed.

In fig. 1, plate VII, the vertical plane of projection cuts the strike of the beds at right angles; A′C′ is the trace and the projection of the face of contact of the two beds; G′A′E′ the trace of two consecutive elements of the channelled fracture.

Upon the horizontal plane, AB is the horizontal of the plane of the beds, which is projected vertically to the point A′; AC is the direction of the System of Fracture.

The specified conditions are i=C′A′D′ and a=BAC.

The normal plane passes through AC, A′C′; its vertical trace is represented by the element A′E′.

Taking an auxiliary plane BF, parallel to the vertical plane XY; it cuts the normal plane in C′D′, CD; drawing through the horizontal of the normal plane A′, it cuts the plane BF in D′. We then draw D′D, and join AD, when the angle BAD is equal to x, and determines the *orientation* of the normal plane, A horizontal section of the grooved fissure through the plane M′A′D′, will give MAD, which is composed of two rectilinear elements:

MA will have the same bearing as the System of Fracture.

AD will deviate by an amount equal to the angle $(x—a)$.

Upon the auxiliary plane BF, we may draw, DH′ parallel to A′E′; LDH′ is the trace of the normal plane. We then draw LFH′ perpendicular to the trace DL, and make the intersections follow L′H′. The angle H′L′F′=Pm is the dip of the normal plane.

Let us calculate x and Pm.

Taking AB=1, we have

$$BC=\text{tang } a \text{ and } BD=\text{tang } x.$$

In the rectangular triangle A′C′D′:

$$A'D'=\text{tang } x \text{ and } A'C'=\text{tang } x \cos i.$$

In the rectangular triangle A′G′C′, we have

$$G'C'=\text{tang } a=A'C' \cos i$$

and consequently

$$\text{tang } a=\text{tang } x \cos^2 i$$

and finally

$$(1) \qquad \text{tang } x=\frac{\text{tang } a}{\cos^2 i}$$

The rectangular triangles H′FD and H′FL′ equal H′F:

$$L'F \text{ tang P}m=DF \text{ cotang } i$$

Now, in the rectangular triangle DLF, we have

$$DF=\frac{LF}{\cos x}=\frac{L'F}{\cos x}$$

removing the common factor in the preceding equations, we have

$$(2) \qquad \text{tang P}m=\frac{\text{cotang } i}{\cos x}$$

Squaring the term cos x to correspond with its value in (1), we have

$$\cos^2 x=\frac{1}{1+\text{tang}^2 x}=\frac{1}{1+\frac{\text{tang}^2 a}{\cos^4 i}}=\frac{\cos^4 i}{\cos^4 i+\text{tang}^2 a}$$

$$\text{tang}^2\text{P}m=\frac{\cos^2 i}{\sin^2 i \times \cos^2 x}=\frac{\cos^4 i+\text{tang}^2 a}{\sin^2 i+\cos^2 i}$$

from whence we derive

$$(3) \qquad \text{tang } Pm = \frac{\sqrt{\cos^4 i + \text{tang}^2 \alpha}}{\sin^2 i \cos^2 i}$$

The formula (1) gives us the bearing of the *normal* plane referred to the plane of the beds; (2) and (3) illustrate its dip below the horizon; the two first may be calculated by logarithms. It is convenient to commence with the first calculation, because the determination of the tang x gives at once the logarithm of cos x for (2).

It will be useful to know the angular value $(x—\alpha)$, *i.e.* the horizontal deviation which the fissure experienced in passing from one bed to the other; the calculation of x by the formula (1) leads in the most simple manner to the difference $(x—\alpha)$.

For every positive value of i, which is less than 90°, we see (1) that the deviation, which is nothing when $\alpha=0_0$ is again nothing when $\alpha=90°$; it will be interesting to ascertain its maximum $(x_1—\alpha_1)$.

We first express $(x—\alpha)$ in terms of i and α.

$$\text{tg } (x—\alpha) = \frac{\text{tg}x — \text{tg}\alpha}{1 + \text{tg}x . \text{tg}\alpha} = \frac{\frac{\text{tg}\alpha}{\cos^2 i} — \text{tg}\alpha}{1 + \frac{\text{tg}^2\alpha}{\cos^2 i}} = \frac{\sin^2 i \text{ tg}\alpha}{\cos^2 i + \text{tg}^2 \alpha}$$

or

$$(4) \qquad \text{arc } (x—\alpha) = \text{arc tang} \left(\frac{\sin^2 i \text{ tg } \alpha}{\cos^2 i + \text{tg}^2 \alpha} \right)$$

or again

$$(4a) \qquad (x—\alpha) = \text{arc tang} \left(\frac{\sin^2 i}{\frac{\cos^2 i}{\text{tg } \alpha} + \text{tg } \alpha} \right)$$

To obtain the minimum of the denominator, I take tang $\alpha_1 = z$; then

$$\frac{\cos^2 i}{z} + z = y \qquad z^2 — yz \times \cos^2 i = 0 \qquad z = \frac{y}{2} \pm \sqrt{\frac{y^2}{4} — \cos^2 i}$$

from whence, cancelling the radical by $y=2 \cos i$, we derive

$$z = \cos i, \text{ or tang } \alpha_1 = \cos i$$

The maximum is then

$$(5) \qquad (x_1—\alpha_1) = \text{arc tang} \left(\frac{\sin^2 i}{2 \cos i} \right)$$

In table II, included in this note, I have calculated the values of a_1 for inclinations of 10°, 20°, 30°, 40°, 45°, and 50°, when tang $a_1 = \cos i$, and the maximum deviations deduced from formula (5).

Returning to the dip Pm, formulæ (2) and (3), for every positive value of i which is less than 90°, it is evident either by the formulæ or on inspection of the figures that Pm increases from 90°—i to 90°, whilst a varies from 0° to 90°.

In table II, attached to this note, I give for inclinations of 10°, 20°, 30°, and 40°, the corresponding values of Pm calculated by the formula (2) $\text{tang Pm} = \frac{\text{cotan } i}{\cos x_1}$; *i.e.* the respective slopes of the normal planes of which the *orientation* x_1 involves the maximum of horizontal deviation $(x_1 - a_1)$.

The complete mathematical discussion of the preceding formula is here unnecessary.

2nd.—In most mining countries the strata are more or less inclined, but their inclination is very rarely greater than the mean dip of the lodes.

In Cornwall, the mean values of i are between 20° and 40°, whilst the east and west lodes dip about 70°, and the north and south cross-courses about 80°.

Let us take for an example a case where $i = 30°$ and a varies from 0° to 90°. Admitting that the opening is *vertical* in the rocks of medium hardness, and that in the very hard strata it exactly follows a normal plane, it will belong to the Fc group of lodes, which dip contrary to the dip of the strata.

When $a = 0°$ the flutings *(cannelures)* are horizontal, $(x - a)$ is nothing and there is no deviation; $\text{P}m = 90° - i = 60$; the difference (Pr—Pm) between the vertical (rich) parts and the inclined (poor) parts is 30°.

When a varies from 0° to 40° 53′ 30″$= a_1$, the flutings are inclined; $(x - a)$ is sensible, and attains a maximum of 8° 13′; Pm is increased from 60° to 69° 18′. The projection of the flutings diminishes, and the difference (Pr—Pm) is reduced from 30° to 20° 42′.

When a increases from a_1 to 90°, $(x - a)$ falls from 8° 13′ to 0°, and Pm increases from 69° 18′ to 90°, the difference (Pr—Pm)

falls from 20° 42′ to 0°, and the flutings disappear both in plan and section. We have thus passed by hypothesis from horizontal flutings parallel to the strata to a vertical plane which is perpendicular to them.

In Cornwall, the principal east and west lodes correspond in general to values of a comprised between 0° and a_1 or there about; in the good districts the bearing of the *caunter lodes* is near a_1; finally in the cross-courses, whether barren or metalliferous, a is generally between 70° and 90°.

The preceding figures should only be regarded as indications. It must not be forgotten that the rich parts of the lodes which are enclosed in rocks of moderate hardness, and have proper bearings, are those most nearly vertical, but they are not exactly vertical; on the other hand, the cross-courses although less channelled and more nearly vertical than the lodes, are neither perfect planes nor exactly vertical.

The geometric traces on the contrary allow us to take into account the mean inclinations of the lodes of both kinds (F*c* and F*a*). [See note C].

Let us again consider from a general point of view, the two extreme cases of strata almost horizontal, and of others strongly inclined. The first case is not frequent in Cornwall, but it is that of the lead-bearing Devonian schists to the south of Liskeard; the second case is only exceptionally met with.

1.—When the rocks are nearly horizontal, i being from 0° to about 10°, the distinction between the lodes F*c* and F*a* has no particular interest beyond that of the local phenomena connected with the direction of underlie of different lodes; it is almost the same as regards the variations of a, for the conditions of the normal plane according to which the strata of greatest resistance will be (by hypothesis) broken, only vary within narrow limits. Thus, making $i=10°$.

When $a=0°$, there is no deviation, and Pm=80° 00′.
„ $a=44° 34'$ „ $(x_1-a_1)=0° 53'$, and Pm=82° 56′.
„ $a=90°$, there is no deviation, and Pm=90° 00′.

The rupture of beds of very great resistance, which are at the same time but little inclined, in planes normal to the bedding results in an opening which has practically the same bearing as the System of Fracture, and which is very nearly vertical.

Fig. 5, plate 1, is a cross-section of one of the rich lodes of Alston Moor; here the limestone and quartzose sandstone being beds of great resistance are broken almost at right angles to their bedding, whilst the soft shales form the oblique component of the mean dip.

Instead of alternating strata presenting very great differences of quality, let us consider the case of beds of schists, some of which are of moderate hardness, and others soft, a being nearly 90°. It is evident that the more resisting strata will be broken more nearly vertical than the others, and that the opening will have a "proper bearing."

2.—When the rocks are much inclined, i being from 50° to 70°, it is necessary to distinguish between the two sets of fissures Fc and Fa; the *allures* of the fissures vary greatly with the values of a.

Let us examine briefly how the openings Fa are likely to be produced.

If a is small, the different beds having but little adhesion may become to some extent separated one from another, so producing a flat intercalated lode (*filon couche*) entirely or in great part comprised between two beds which may be of a nature either identical or of different composition; the phenomena of rupture are replaced by those of separation. When a is greater, the two modes of fissuring may appear alternately in the same fissure; great inflexions in direction then result, and the production of extremely numerous branches.

As a becomes still greater, there is sometimes produced a series of lenticular masses or rich columns obliquely attached to a thin vein of little value; true contact deposits connected together by the fissure, the production of which depends upon the degree of facility with which the beds are separable one from another.

As to the openings Fc; if a is small, the inclination of the normal plane is about $90°—i$. When a is from 20° to 40°, a circumstance unfavorable to the slipping of the region of the hanging wall, the flutings (*cannelures*) will have just such an amount of projection as is due to the physical qualities of the different beds; *i.e.* may present sufficient, but not exaggerated differences.

As α becomes greater, Pm increases very rapidly; the following figures will serve to shew the successive positions which the normal plane will assume.

$i=50°$

$\alpha=32° 44'=(\alpha_1)$; $(x_1-\alpha_1)=24° 32'$; the maximum deviation.
$\alpha=50$ .. .. $x-\alpha=20$ 53 ; Pm=68° 40'.
$\alpha=60$ .. .. $x-\alpha=16$ 35 ; Pm=74 32.
$\alpha=70$ .. .. $x-\alpha=11$ 27 ; Pm=79 57.

Considered as a whole, the fissure will tend to exhibit variations very considerable in direction, but moderate in underlie.

It is beyond my purpose to follow up these general considerations, but I would here draw special attention to the fact that the phenomena of fracture, although produced by *vertical forces*, become more complex in proportion as the rocks acted upon are more inclined.

In Table I, I give numerical values to the positions of the normal plane, in cases where $i=40°$, 45°, 50°, and 60°; and where $\alpha=50°$, 60°, or 70°. These numbers may suggest useful approximations, but should only be applied with judgment.

TABLE I.

Bearing of the fracture(α_1) which for each value of i corresponds to the greatest horizontal deviation; value $(x_1-\alpha_1)$ of this maximum deviation, the rocks being fractured in planes normal to the bedding.

Inclination of the beds (i).	Bearing (α_1) according to the formula tg. $\alpha_1=\cos i$.	Deviation $(x_1-\alpha_1)$ by formula (5).	Observation.
10°	44° 33′ 40″	0° 52′ 40″	The values of α_1 and $(x_1-\alpha_1)$ are calculated within 10″.
20°	43 13 10	3 33 40	
30°	40 53 30	8 12 50	
40°	37 27 10	15 5 30	
50°	35 15 50	19 28 10	
60°	32 43 50	24 32 00	

TABLE II.

Underlie of the normal plane which corresponds with a maximum of horizontal deviation.

Inclination (i).	Bearing (x_1) obtained by adding a_1 to ($x_1 - a_1$) in Table I.	Dip or Underlie by the formula (2) $\tang Pm = \frac{\cotg i}{\cos x}$	Excess of Pm over $90° - i$.
10°	45° 26′ 20″	82° 56′ 20″	2° 56′ 20″
20	46 46 50	75 58 20	5 58 20
30	49 6 20	69 17 40	9 17 40
40	52 32 40	62 57 50	12 57 50

TABLE III.

Bearing, deviation, and underlie of the normal plane in much inclined strata, when the strike forms angles of 50°, 60°, or 70° with the System of Fracture.

Inclination i.	a.	x by formula (1) $\tang x = \frac{\tang a}{\cos_2 i}$	Deviation ($x - a$) of the horizontal of the normal plane.	Dip Pm of the normal plane by formula (2) $\tang Pm = \frac{\cotg i}{\cos x}$	Excess of Pm over $90° - i$.
40°	50°	63° 47′ 0″	13° 47′ 0″	69° 39′ 40″	19° 39′ 40″
	60°	71 17 0	11 17 0	74 55 50	24 55 50
	70°	77 55 0	7 55 0	77 31 50	27 31 50
45	50°	67 14 20	17 14 20	68 51 0	23 51 0
	60°	73 32 30	13 32 30	74 10 50	29 10 50
	70°	79 41 10	9 41 10	79 50 50	34 50 50
50°	50°	70 52 40	20 52 40	68 40 30	28 40 30
	60°	76 35 0	16 35 0	74 32 30	34 32 30
	70°	81 27 0	11 27 0	79 57 40	39 57 40
60°	50°	78 9 10	28 9 10	70 25 30	40 25 30
	60°	81 47 10	21 47 10	76 6 0	46 6 0
	70°	84 48 0	14 48 0	81 4 40	51 4 40

NOTE C.

Description of the Diagrams of Lodes Fc *and* Fa, *Plates IV & V.*

PLATES IV and V contain diagrams of two fissures in the same country rocks, both of which are due to the same system of fracture, although one is inclined in the same direction as the strata, and the other in an opposite direction.

The beds are supposed to be alternately good and bad, and of equal thickness; their inclination (i) is 40°

The system of fracture makes an angle (a) of 32° with the strike of the beds.*

Lode Fc, Fig. 3, *Plate IV.* The horizontal plane is parallel to the direction of the beds, and the vertical plane is at right angles to that direction.

$A'\beta\gamma$ is the junction of two beds, the lower one being of (good) moderate hardness, and the upper too hard, and therefore bad. The upper bed is ruptured at right angles to the bedding, but the lower one in a plane $\rho\ \omega$ whose bearing is that of the system of fracture, and inclined 82° to the horizon. Of the two faces of the flutings (*cannelure*), therefore, the most upright will make an angle of 32° (a) with the bearing of the System of fracture, and its dip (Pr) will be 82°, while the flatter face will be at right angles to the bed, and its slope will be (Pm_1) 50°, or complementary to (i).

I draw $\omega\ \rho'$ so that the plane $\rho\omega\rho'$ dips 82°; $Y\omega\rho'$ then gives the apparent dip $Pr_1 = 80°$ of the more upright element of the lode, as drawn in cross-section.

The straight line $A'\beta\ A\delta$ is the intersection of the planes $\gamma\beta A'$ and $\rho\omega\rho'$; it is this which, with the normal $A'E'\ AE$ defines the normal plane.

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* The values of a and i adopted above, though rather greater than the averages observed in Cornwall, are convenient for shewing clearly by the diagrams the changes of underlie and of bearing observable in the actual workings. From the arrows on the Plates, the "strike" is supposed to coincide with the system of Westmoreland, E 40° ½ N; and the system of fracture is that of the Land's End, E 8° ½ N—the difference a being 32°.

I draw through A$'$ the vertical trace ν A$'$B, making A$'$BY$=50^\circ$ $=$Pm_1; I then join δ B and produce it to μ. The normal plane μ B ν then makes with the horizontal plane an angle P$m=58^\circ$ and finally its horizontal trace makes with the strike of the beds an angle $\alpha'=42\frac{1}{2}^\circ$.

The *deviation* in the levels in passing from the good bed to the bad is $(\alpha_1-\alpha)=10\frac{1}{2}^\circ$; and in cross-section the *inflexion* is given by (Pr—Pm)$=24^\circ$.

Lode Fa, *Fig.* 4, *Plate IV.* The faces of the *cannelures* make the same angles as those already given for the lode Fc, only the respective inclinations are reversed. We take, therefore, once more P$r=82^\circ$ and P$m=58^\circ$, and consequently (Pr—Pm)$=24^\circ$. I then draw $\rho\omega\rho'$, and through the straight line A$'\beta$ Aδ I draw μ B ν dipping 58°. Its vertical trace Aν' then completes with A$'\omega$ the two elements of the apparent profile. I then make νBX$=$P$m_1=57^\circ$; then P$r_1=80^\circ$ and $\alpha_1=19^\circ$,* from which we have the *deviation* $(\alpha-\alpha_1)=13^\circ$.

Figures 5 and 6 are vertical and horizontal sections, the object of which is the determination of the *mean plane of the lode*, *i.e.* its mean *direction* and its mean *dip*.

In Fig. 5, a section through AB, Fig. 6, the beds are cut through normally, and the apparent profiles of Fc and Fa are drawn according to the values of Pr_1 and Pm_1 adopted in Figs. 3 and 4.

The section Fig. 6, through A$'$B$'$ Fig. 5, shews two levels—the respective "elements" of which follow the System of fracture in the good beds, and deviate in the bad ones $10\frac{1}{2}^\circ$ for the lode Fc and 13° for Fa.

The two straight lines drawn respectively through the summits of these broken lines are the horizontals of the two mean planes; the analagous lines in the vertical section Fig. 5, give the mean *apparent* dips P$_1$. Finally, the constructions of Fig. 7 give the true dips of the mean planes.

The principal conditions and results are given below:—

Common Conditions for the two Lodes Fc, Fa.

ROCKS.	LODES.
Beds of equal thickness.	Equality of (Pr—Pm).
$i=40^\circ$	$\alpha=32^\circ$

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* Erratum: Fig. 4, Pl. iv, for $42\frac{1}{2}^\circ$ read 19°.

Fc { The steeper faces of the *cannelures* dip (P*r*) 82°
The flatter faces are normal to the strata—hence P*m*=58°

Fa { P*r* and P*m* have the same value, but the dip is in reverse directions.

Results.

1*st.*—*Relative bearings, or angles formed with the direction of the strata.*

	Level on F*c*	Level on F*a*
Rich part	$a=32°$	$a=32°$
Poor part	$a'=42\frac{1}{2}°$	$a'=19°$
Mean direction	37°	24°

From which we deduce:—

	F*c*	F*a*
Real deviation observed in passing from good to bad beds	10½°	13°
Apparent deviation of the mean direction of the lode from the bearing of the Systemof Fracture	5°	8°
2nd.—*Mean Dip (P)*................	71°	66½°
3rd.—*Value of* (*Pr—Pm*)	24°	24°

The mean directions of the lodes include an angle of 5° + 8° = 13°; their junction dips in the same direction as the strata. The bisectrix of this angle of 13° differs only $\frac{8°-5°}{2}=1\frac{1}{2}°$ from the bearing of the System of fracture; it makes an angle of 30½° with the strike of the beds.

Plate V gives for each of these two lodes, in Figs. 1 and 5, the plans or geometric representations of the necessary conditions for constructing the diagrams. Figs. 2 and 6 are cross-sections through a vertical plane, perpendicular to the mean plane of the lode. Figs. 3 and 7 are vertical projections of the lode, on a plane parallel to the mean direction. Figs. 4 and 8 are plans of a series of levels 10 fathoms apart. It will suffice to describe with some detail Figs. 1 to 4, relating to F*c*, and to indicate the differences observable in F*a*.

Diagrams of F*c* Fig. 1.—The median plane of the lode coincides with the horizontal line XY; its trace upon a second vertical plane ZV is AF*c*, making with ZV the angle VAF*c*=71°; SA is the horizontal trace of the plane of contact of two beds; then SAX=37°. This plane makes an angle $i=40°$ with the horizontal plane; I then determine the vertical trace AT of its intersection by the plane C*be* making *bef*=40°, erecting the perpendicular *f* on C, and producing ACT.

The auxiliary plane CB parallel to ZV, gives upon this latter the projection B_2 C_2 of its intersection by the plane of the beds; a_2 is the point of intersection of this latter plane by the median plane of the lode. I bring round a_2 by the dotted lines to a', project it to a and join A*a*′ I′ and A*a*I; these lines are the projections of the intersection of the plane of the beds by the median plane of the lode. Bringing down AI upon the vertical plane, I take A*a*″R which gives the angle XAR as the inclination of the metalliferous zones (*shoots*) beneath the horizon.

The diagram is completed by representing upon the horizontal plane, the traces of two consecutive beds of equal thickness, *eg*, *gh*, and indicating upon ZV the section of their beds by BC.

In Fig. 2, the horizontal traces of the planes of fracture of the good and bad beds make with XY of fig. 1 angles of only 5° and 5½°, the intersection of these planes by the plane BC perpendicular to XY gives for them lines whose inclinations differ very little from the maxima P*r* and P*m*.

The profile may then be constructed with sufficient accuracy by reproducing in this figure the section of the beds projected upon ZV in fig. 1, making the line of the greatest slope of the mean plane of the lode=71°=P, and then tracing the elements of the broken line, so that they differ little from the values P*r*=82° and P*m*=58°.

Fig. 3 shews the inclined *cannelures* of the fracture; their inclination is given by the angle XAI′ fig. 1, and the separation of the ridges by the vertical projection of the profile fig. 2. The zones opened in the good beds are indicated by the letters AA—BB, &c. The equidistant horizontal lines are levels supposed to be driven in the lode. In this fig. the foot-wall is supposed to have been removed, the hanging wall facing the spectator.

In Fig. 4, the rich columns or shoots AA, BB, &c., are drawn parallel to AI fig. 1; the elements of the broken lines in the *shoots* make angles of 5° with the mean direction XY, and in the poor parts angles of 5½° on the other side, corresponding to a total deviation of 10½°.

In this diagram the elements are evidently identical, their separation is derived from the combined projections given in figs. 2 and 3. In this figure the hanging wall is supposed to be removed.

Diagrams of F*a*.—In fig. 5, XAF*a* is the mean plane of the lode where ZAF*a*=66½° ; SAT is a plan of the beds SAX=24°, and *i*=40° ; the construction of AI, AI′, and AR is as in fig. 1.

Fig. 6 is constructed from the plan ZV fig. 5 ; the specified conditions being P=66½°, P*r*=82°, and P*m*=58°.

In fig. 7, the hanging wall is supposed to be removed so that the fissure recedes from the observer; the columns AA, BB, &c. are inclined as at AI′ fig. 5.

In fig. 8, the rich columns or shoots AA, &c., have the same bearing as AI in fig. 5 ; the elements of the levels make in the shoots, angles of 8° on one side of the mean direction, and those of the bad parts, angles of 5° on the other side, giving a total deviation of 13°. In this diagram also the hanging wall is supposed to be removed.

Comparing the essential numbers which result from figs. 1 and 5, we have

		Angular Values.	Lode F*c*.	Lode F*a*.
Specified conditions	Mean Plane .	Bearing SAX	57°	24°
		Dip	71	66½
Results ..	Cross-section.	Apparent inclination of the country reduced to	34	37
	Shoots	Inclination XAI′ (in vertical projection)..	23	26½
		Bearing XAI (in horizontal projection) ..	8⅓	11⅓
		Dip XAR (true)	22½	26

The following useful numerical results may be deduced from approximate measurements of the figures.

For each 100 fathoms of level driven in a rich part, there would be in hard rock, and in a poor part of the lode about 78 fathoms to drive in a lode F*c*, and 170 fathoms in a lode F*a*.

Out of each 100 fathoms of inclined shaft or winze, sunk on the course of the lode, and at right angles to the mean plane, there would be

	F*c*.	F*a*.
fathoms sunk in rich parts..	51·0	32·5
,, ,, poor parts..	47·5	69·0
Total	101·5	101·5

For an equal depth sunk, and an equal extent of drivage, there would be for each 1,000 superficial fathoms opened in bad beds about 1,136 fathoms laid open in good beds in a lode F*c*, and only 407 fathoms in a lode F*a*. A comparison of these two latter numbers shews that for an equal development of workings, both in depth and length, the surface of the rich parts in a lode F*c* would be, in the case illustrated by the diagrams, much more than double that of the rich parts of a lode F*a*.

NOTE D.

On the numerical conditions of the eleven Ancient Systems in Cornwall, and on the values of the Angular Deviations which are likely to be met with in following the poor zones of the lodes.

THE table of the first nineteen Systems of Mountains represented by the corresponding great circles of the Net-work of Elie de Beaumont, transported to the point a^{IV} in the neighbourhood of the Land's End, has been already published.* The bearing of each System is there calculated to the hundreth of a second. I reproduce the table here, taking the nearest minutes. In the third column I have supplied the perpendiculars (see Table 1 to note D).

The eleven ancient Systems have predominated in the formation of the rocks and lodes of Cornwall. In studying their influence, it is important to keep before us the angles formed by these Systems taken in pairs. It will suffice to calculate the acute angles so included; the *position* of this angle upon the complete circle may then be indicated by a single number, viz.: the bearing of the bisectrix. It is then easy to determine the obtuse supplementary angle, and the bearing of its bisectrix, which is perpendicular to the first.

The eleven ancient Systems thus considered, yield 132 distinct bearings of more or less importance as under.

Systems		11
Perpendiculars to the Systems..		11
Bisectrices of the acute angles ..	$\frac{11 \times 10}{2}$	55
Perpendiculars to these = bisectrices of the obtuse angles		55
Total		132

The following observations will shew the use of these calculations.

With regard to upheavals of the stratified rocks, the *System* concerned in first raising the strata impressed its direction very strongly, not only by determining the strike of the beds, but also by giving rise to a great number of joints, fissures, and openings; and, simultaneously, the perpendicular to the System was marked by the production of transverse joints and fissures.

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* *Comptes rendus.* LV, p. 759, 17 Nov., 1862, and *Annales des Mines,* 6th series, vol. III, p. 161; 1863.

These are the *direct* effects of the system. They occur more especially in sedimentary formations, and in a well-formed rock they generally exist in spite of the complications which result from analagous phenomena which have occurred previously in the underlying rocks, and from the fractures due to more recent Systems.

But in the very anceint rocks of the west of Cornwall, after the first raising of the schists, many other upheavals took place having different bearings, and these have masked, if they have not effaced the *direct effects* of the more ancient System. Then, when the ground had been fissnred and fractured in different directions, the later Systems in many cases reopened the fissures already formed, so that they are only indicated by a very small number of fissures, having their own proper bearing. Their effects were especially relative. This utilization of the fissures and openings previously formed resulted from the distribution of the new forces taking place symmetrically into them. A consideration of the two groups of bisectrices enables us to understand this order of phenomena, which, although doubtless of secondary importance in many mining districts, has largely contributed to the riches as well as the complexity of a great number of deposits in Cornwall.

Table 11 of this note gives these angles in two successive columns, entitled East and West Systems, and North and South Systems respectively. The first results from a calculation of the angles included between the six East and West Systems, Finistère, Morbihan, Westmoreland, Land's End, Ballons, and Pays Bas, taken in pairs, each system being considered successively with all the anterior systems. In designating each angle, the first name in the third column, is that of an East and West System, while the second may be either East and West, or North and South; it is evident, however, that the smallest angles must be comprised between two East and West Systems.

The second column is formed in an analagous manner, by taking for points of departure the North and South Systems (Vendée, Longmynd, Forez, North of England, (for which we have substituted here the octahedric of Mulehacen)—and Rhine.

The angles are ranged in order of magnitude, they form in the two columns four natural groups, whose limits are 0° to 20°, 20° to 50°, 50° to 70°, and 70° to 90°, there being gaps of from 5° to 11° between each group.

In the third table, I give by way of example an application of the formula $x=\frac{\text{tang } a}{\cos^2 i}$ (See Note B). I have chosen a case where the strata have the bearing of the System of Finistère E 21° 46′ N (or nearly E.W magnetic), a dip of 30°, and are fissured by the five other E.W Systems. The fissure by our hypothesis is contained in one kind of "country," dips contrary to the dip of the rocks, and cuts through the bad beds in a normal plane to their bedding. In horizontal projection the deviating element of a level will be indicated by the horizontal of this normal plane. According to the expressions already adopted, we have

a=Angle between Finistère and each System of upheaval.

x=Angle between Finistère and the horizontal of the normal plane.

$x—a$=The angular deviation observable in the level in passing from a rich to a poor part of the lode. The *turn* or *warp* is in no way abnormal unless it sensibly exceeds the amount indicated in the third column; the inclination i continues to be taken at 30°, and the bad beds are supposed to be very hard.

If the observer has determined the strike and dip of the enclosing rock, and the proper bearing of the lode F*c*, *i.e.* that of its normal rich parts, he possesses the elements a and i, and may calculate the maximum deviation $x—a$, possible in that particular case. Even before a is known, an observation of the inclination i will give him an indication of the absolute maximum $x_1—a_1$ which is inserted in table I, note B. In the example before us where $i=30°$ the value of $x_1—a_1=8° \ 12' \ 50''$.

In the fourth table I have set down the calculated *orientations* of the lode F*c* referred to in the preceding table, and added those of the deviations obtained geometrically in considering each system successively as the cause of an upheaval of a rock which has been fractured by East and West Systems of later periods. The value of i is still taken at 30°. The column of the deviations of F*a* has been filled up by merely supposing the deviations to be equal to those of the lode F*c*, but in a contrary direction, hence the opposite dips of the poor parts are taken as having the same absolute value.

The last column, under the heading of included angles, contains the double of the deviation.

The results given in tables III and IV are exact for the openings F*c*, and are based upon the values of *i* and *a* which define the normal plane.

If, in addition to these specified conditions, the observer knows the dips P*r* and P*m* of the lodes F*c* and F*a* in both good and bad beds, he can then make use of the mode of geometric projection developed in note C.

I will now define the assistance which is rendered by these calculations, or by the traces of the deviations.

In cases where the constancy of the qualities and surroundings of the beds conduces to regularity in the phenomena of fracture, and to precision of observations, the results of calculations, and of geometric construction are often exactly realized in practice.

But, more often, the variations of the natural conditions only allow us to obtain from geometry a knowledge of the direction, and the probable extent of the deviations; but even this knowledge may be very useful.

The lode, or that " element " of the lode which is under observation, is *attributable to a System of Fracture;* when the miner is following a level, he may expect to follow the direction of the System in the normal rich parts (or parts of "proper bearing"), and he may equally expect to leave that direction when he enters a part where the lode is poor and thin; this *normal sterility* corresponds to a somewhat regular deviation, which it is very interesting to know.

If he were not to take account of the good and bad directions in each lode, the miner would be constantly liable to fall into great confusion, and to see sometimes a series of Systems in the natural effects of only one, at others only one in the combined natural effects of several distinct Systems. Such errors would be still greater than those which result at the present time from the use of *mean* directions.

The diagram fig. 2, plate VII, shews certain coincidences which are merely *apparent* in the direction of the deviations from certain Systems. It includes, in three columns, intitled Land's End, Ballons, and Pays Bas respectively, certain horizontal lines placed according to the values taken from the fourth table in this note. Each column is subdivided for the openings F*c* and F*a*, and to the right of each is inserted the initial of the System of upheaval of the enclosing rocks.

An examination of this diagram shews that the angle of 26° 46′ made by the Systems Finistère and Ballons, includes the bearings of Pays Bas and Land's End, but the deviations (taken from table IV, where *i* is only 30°) of Pays Bas overlap the bearings of Finistère and Land's End; and those of Land's End overlap the Pays Bas System, and some of the deviations from that of Ballons. The coincidences might be rendered still more evident by comparing the deviations produced in rocks of different inclinations.

If we return to a case of equal inclination, and consider fissures in stratified rocks caused by only one System, the confusion is much lessened, and it disappears altogether when we take into account the *direction* of the dip of the openings F*c* and F*a*. For example,

1. In a stratified rock upheaved by the System Finistère, the deviation from the Land's End, may amount to E 12½° N; that from Pays Bas may be as little as E 13° N, but the first belongs to an opening F*a*, the second to an opening F*c*.

2. In a rock upheaved by the System of Morbihan, the divergence from Land's End may be as little as E 0½° N, and that of Ballons may be E 2½° N. There may be a coincidence of bearing or even an overlapping, but here also the *underlies* are opposed.

The preceding details may serve as a caution against observations, which are well made, but badly interpreted; they shew how important it is to the miner to determine the "proper bearing;" *i.e. the characteristic element of all the fissures formed by one System*, the true guide through the varied conditions of the openings caused by the modifications to which the enclosing rocks have been subjected, not only in different districts, but often even within the limits of one "sett."

A knowledge of the stratigraphy of the ancient Silurian and Devonian schists of Cornwall is therefore indispensible to a study of the directions taken by the different lodes in the different districts of the county, and conduces to an appreciation of the *details of construction* of each lode.

I.—Table of the nineteen most ancient mountain systems, with their perpendiculars, transferred to the point a^{IV}. *

NAMES OF THE SYSTEMS.	BEARINGS AT THE POINT a^{IV}	
	SYSTEMS.	PERPENDICULARS.
Vendée	N. 26° 13′ W.	E. 26° 13′ N.
Finistère	E. 21 46 N.	N. 21 46 W.
Longmynd...	N. 20 15 E.	W. 20 15 N.
Morbihan	W. 36 13 N.	N. 36 13 E.
Westmoreland	E. 40 24 N.	N. 40 24 W.
Land's End	E. 8 23 N.	N. 8 23 W.
Ballons	W. 5 0 N.	N. 5 0 E.
Forez	N. 23 22 W.	E. 23 22 N.
Nord de l'Angleterre	N. 8 7 W.	E. 8 7 N.
Pays-Bas	E. 14 55 N.	N. 14 55 W.
Rhin	N. 10 26 E.	W. 10 26 N.
Thuringerwald	W. 26 57 N.	N. 26 57 E.
Mont-Seny	N. 28 6 E.	W. 28 6 N.
Côte d'Or	N. 38 54 E.	W. 38 54 N.
Mont-Viso	N. 32 35 W.	E. 32 35 N.
Pyrénées	W. 11 15 N.	N. 11 15 E.
Corse et Sardaigne	N. 12 51 W.	E. 12 51 N.
Ile de Wight	E. 14 48 N.	N. 14 48 W.
Vercors	N. 1 40 W.	E. 1 40 N.
Octaédrique du Mulchecen	N. 8 23 W.	E. 8 23 N.

II.—Tables of the angles included by the eleven ancient systems at the point a^{IV}.

GROUPS.	ANGLE.	NAMES.	BISECTRIX.	Number.
		EAST & WEST SYSTEMS.		
from 0° to 20°	6° 32′	Pays-Bas—Land's End	E. 11° 39′ N.	
	6 51	Pays-Bas—Finistère ...	E. 18 39 N.	
	13 23	Land's End—Finistère	E. 15 5 N.	
	13 23	Ballons—Land's End ...	E. 1 41 N.	
	18 38	Westmoreland-Finistère	E. 31 5 N.	
diff. 5° 24′	19 55	Pays-Bas—Ballons... ...	E. 4 57 N.	6

---

* The geographical position of the point a^{IV} is
Latitude 50° 25′ 46″ 67 N.
Longitude 5° 49′ 53″ 75 W. of Greenwich.

The situation of point a^{IV} in the European pentagon is given in fig. 10, Plate VIII; it is determined by the rectangular intersection of two principal circles, which M. Elie de Beaumont has named the Primitive of the Land's End, and the Octahedral of Mulehacen.

The bearing of the primitive of the Land's End at a^{IV} is E. 8° 23′ 9″. 85 N. The point a^{IV} is a little N. and W. of the Longships Lighthouse, the lengths of the perpendiculars dropped from this lighthouse upon the two great circles are respectively as follows:—From the lighthouse northward, to the primitive circle 40·710 metres; from the lighthouse westward, to the octahedral circle 765 m.

Table II *continued.*

GROUPS.	ANGLE.	NAMES.	BISECTRIX.	Number.
EAST & WEST SYSTEMS.				
from 20°to 50° diff. 5° 34′	25 29	Pays-Bas-Westmoreland	E. 27 39 N.	8
	26 46	Ballons—Finistère	E. 8 23 N.	
	27 34	Morbihan—Vendée	N. 40 0 W.	
	29 21	Westmoreland—Longmynd	N. 34 56 E.	
	31 13	Ballons—Morbihan	W. 20 36 N.	
	32 1	Land's End—Westmoreland	E. 24 23 N.	
	44 36	Land's End—Morbihan	W. 13 55 N.	
	45 24	Ballons—Westmoreland	E. 17 42 N.	
from 50 to 70° diff 10° 18′	51 8	Pays-Bas—Morbihan ...	W. 10 39 N.	5
	54 50	Pays-Bas—Longmynd ...	E. 42 20 N.	
	57 59	Morbihan—Finistère ...	W. 7 13 N.	
	58 47	Ballons—Vendée	W. 34 23 N.	
	61 22	Land's End—Longmynd	E. 39 4 N.	
from 70°to 90°	72 10	Land's End—Vendée ...	W. 27 42 N.	9
	74 2	Morbihan—Longmynd ...	N. 16 46 W.	
	74 45	Ballons—Longmynd ...	E. 32 22 N.	
	75 49	Westmoreland—Vendée	N. 11 41 E.	
	76 37	Westmoreland-Morbihan	E. 2 6 N.	
	78 42	Pays-Bas—Vendée	W. 24 26 N.	
	81 33	Pays-Bas—Forez	W. 25 41 N.	
	83 28	Pays-Bas—Nord Angleterre	N. 33 21 E.	
	85 33	Finistère—Vendée	W. 21 0 N.	
NORTH & SOUTH SYSTEMS				
from 0° to 20° diff. 9° 49′	2° 51′	Forez—Vendée	N. 24° 47 W.	5
	9 49	Rhin—Longmynd	N. 15 20 E.	
	14 59	Nord Angleterre—Forez	N. 15 52 W.	
	17 50	Nord Angleterre-Vendée	N. 17 18 W.	
	18 49	Rhin—Nord Angleterre	N. 1 1 E.	
from 20° to 50° diff. 9° 49′	28 38	Nord Angleterre—Longmynd	N. 5 56 E.	9
	30 25	Forez—Morbihan	N. 38 34 W.	
	33 47	Rhin—Forez...	N. 6 28 W.	
	36 39	Rhin—Vendée	N. 7 53 W.	
	39 10	Rhin—Westmoreland ...	N. 30 1 E.	
	43 37	Forez—Longmynd	N. 1 33 W.	
	45 24	Nord Angleterre-Morbihan	N. 31 5 W.	
	46 29	Longmynd—Vendée ...	N. 3 0 W.	
	47 59	Longmynd—Finistère ...	E. 45 45 N.	

Table II. *Continued.*

GROUPS.	ANGLE.	NAMES.	BISECTRIX.	Number.
		NORTH & SOUTH SYSTEMS.		
from 50° to 70°	57 48	Rhin—Finistère	N. 39 20 E.	
	57 59	Nord Angleterre—Westmoreland	N. 20 36 E.	
	61 38	Forez—Ballons	W. 35 49 N.	
	64 13	Rhin—Morbihan	N. 21 40 W.	
	64 39	Rhin—Pays-Bas	N. 42 45 E.	
diff. 6° 32′				5
from 70° to 90°	71 11	Rhin—Land's End	E. 43 58 N.	
	72 58	Forez—Westmoreland ...	N. 13 7 E.	
	75 1	Forez—Land's End... ...	W. 27 7 N.	
	76 37	Nord Angleterre—Finistère	N. 29 55 E.	
	76 37	Nord Angleterre–Ballons	W. 43 18 N.	
	84 34	Rhin—Ballons	E. 37 17 N.	
	88 24	Forez—Finistère	W. 22 26 N.	
	90 0	Nord Angleterre—Land's End	N. 36 37 E. W. 36 37 N.	
				8

III.—Table of the deviations from the five East and West Systems of Morbihan, Westmoreland, Land's End, Ballons, and Pays-Bas, with their bearings, which appear as fissures F*c* following normal planes in the bad beds of a formation, the strike of which is that of Finistère, and the dip 30°. This table is calculated by the formula tg $x=\frac{\text{tg}\, a}{\cos^2 i}$ [Note B].

$i=30°$

FINISTÈRE AT THE POINT a^{iv}, E. 21° 46′ N.					
SYSTEM OF FRACTURE.	Angle a	Angle x	Deviation $x-a$	BEARING.	
				GOOD BEDS.	BAD BEDS.
Morbihan	57° 59′	64°52′30″	6°53′30″	W. 36° 13′ N.	W. 43°6′30″N.
Westmoreland ..	18 38	24 12 10	5 34 10	E. 40 24 N.	E. 45 58 10 N.
Land's End	13 23	17 36 ,,	4 13 ,,	E. 8 23 N.	E. 4 10 ,, N.
Ballons	26 46	33 55 20	7 9 20	W. 5 ,, N.	W. 12 9 20 N.
Pays-Bas	6 32	8 40 50	2 8 50	E. 14 55 N.	E. 12 46 10 N.

N.B.—The maximum of deviation when $i=30$ will be $x_1-a_1=8° 12' 50''$. It corresponds to $a_1=40° 58' 30''$.

IV.—Table of approximate deviations which the fissures may acquire in strata whose dip is 30°.

Systems of Stratification of the rocks.	Systems of fracture.	Bearings of the levels in the bad beds.			
		Fissures F*c*.		Fissures F*a*.	Included Angles.
Finistère E. 21° 46′ N.	Morbihan ...	W. 43° 6′ N.	Calculated by table III.	W. 29° 20′ N.	13° 46′
	Westmoreland	E. 45 58 N.		E. 34 50 N.	11 8
	Land's End...	E. 4 10 N.		E. 12 36 N.	8 26
	Ballons	W. 12 9 N.		E. 2 9 N.	14 18
	Pays-Bas ...	E. 12 46 N.		E. 17 4 N.	4 18
Morbihan W. 36° 13′ N.	Westmoreland	E. 43° 1/2 N.	Obtained by geometric construction.	E. 37° 1/2 N.	6° „
	Land's End ...	E. 16 1/2 N.		E. 0 1/2 N.	16 „
	Ballons	E. 2 1/2 N.		W. 12 1/2 N.	15 „
	Pays-Bas ...	E. 22 „ N.		E. 8 „ N.	14 „
Westmoreland E. 40° 24′ N.	Land's End...	E. 1° „ N.		E. 16° „ N.	15 „
	Ballons	W. 13 „ N.		E. 3 „ N.	16 „
	Pays-Bas ...	E. 8 „ N.		E. 22 „ N.	14 „
Land's End E. 8° 23′ N.	Ballons	W. 9° „ N.		W. 1° „ N.	8° „
	Pays-Bas ...	E. 17 „ N.		E. 13 „ N.	4 „
Ballons W. 5° N.	Pays-Bas ...	E. 21° „ N.		E. 9° „ N.	12° „

N.B.—The relative values of the openings F*c* have been determined by calculation or from the construction described in Note B; the openings F*a* are supposed to be symmetrical with F*c* as referred to the System of Fracture.

NOTE E.

On taking notes of bearings and directions, and on the use of a compass graduated in octants.

THE engineer who wishes to apply the idea of Stratigraphic Systems to the study of lodes is led to multiply observations of directions; it is therefore important to choose the most simple and appropriate mode of reading and noting the angles observed, and especially as regards the constant use of a compass in subterranean workings. In such matters every mode is good which is easily managed; my aim in describing here that which I have long adopted, is only to facilitate the making of such observations by those who have not been in the habit of doing so.

The ordinary compass is graduated from 0° to 360°, proceeding from the N. point, and the points of the magnetised needle indicate two numbers simultaneously. These angular values, which differ from each other by 180°, both define the bearing of the part under observation, and characterize the direction in which one is looking; *i.e.* the numbers indicate respectively the two opposite directions which would be followed in following the bearing.

For example, if the N. (*blue*) point of the needle indicates 253° (the S. [*white*] indicating 73°), we say that the direction is E 17° S, but when the N. point gives 73° we call it W. 17° N.

This graduation, which is so simple and suitable for all geometrical operations, therefore presents grave inconveniences and a double nomenclature when applied to bearings.

The difficulty may be obviated if we are content to measure the angles upon the half-circle from the right. Many authors have adopted this mode of computation, which facilitates a prompt appreciation and calculation of angular differences. Reading 253° from the N. (blue) point, they note N. 107° E., or simply 107°. But, although this number 107° suffices to characterise the bearing, it leaves the direction undetermined.

To specify this also, we must either say N. 107° E.; or, S. 107° W.

Now the direction followed only makes with an east and west line an angle of 17°. Is it not preferable to replace the number 107° by the number 17°, first naming *the cardinal point towards which one is going?*

To this consideration we may add another, not less valuable in the working of lodes. In every mining country one is led to distinguish the veins whose bearing is near E.W. (magnetic) from those which are near N.S., and from those intermediate or diagonal lodes which are N.E.—S.W., or N.W.—S.E.

The groups of lodes of either kind are included within more or less acute angles, but in the ancient rocks of Europe the Systems of upheaval and of fracture agree specially with such distinctions as *East and West Lodes, North and South Cross-courses, &c.*, adding in many mining districts, *Caunters, quarter-point veins, &c.* Let us see how the proposed graduation takes account of this natural grouping.

Dividing the circle into octants, let us consider the half-circumference situated to the north of the E.W. diameter, fig. 3, pl. VII. Departing from the N. point, marked 0° we read in each of the octants to right and left angles below 45°; we note also 0° at each of the extremities of the E.W. diameter, and we read in the octant comprised between the east and north-east angles form 0° to 45°; finally, we do the same in the fourth octant from west to north-west.

Each bearing will then be defined by one number, which never exceeds 45°. The east and west lodes are found to be subdivided into two natural groups, comprising those which "carry their heads north of east," and others whose bearing is north of west.

Under these conditions, when we designate a System, the first word pronounced defines the kind of lode referred to, just as in Cornwall the term north and south implies a cross-course, and the words east and west give the idea of a lode. With regard to east and west lodes the word gives even the octant, so that the number set down indicates the limits from 0° to 45°, and enables us at once to recognize the *departure* of the bearing of the System from the nearest cardinal point.

As to the direction, it is easy in noting an observation to substitute S. for N. or W. for E. [I use a pocket compass graduated into octants on the principle indicated;* like ordinary compasses, it bears a N.S. line and an E.W. line, but each octant is indicated by a finer line replacing the number 45 on the graduated circle, as in Figs. 3 and 4, Pl. VII.

Two cases may be considered by the reader.

1st. The observed direction belongs to a N.S. group. The angle, which must be less than 45°, is contained between the line of vision, and one of the points of the Magnetic Needle, the color of the point (blue or white) shewing whether it is N. or S.; the number on the graduation then at once indicates the angle included between the observed bearing and the cardinal point, while the relative position of the arrow, to the right or left of the point, whether blue or white, shews whether it is east or west.

2nd. When the observed direction belongs to an east and west group, the angle of less than 45° is included between one of the points marked E. or W., and observing which point of the needle is opposite to one of these, we *see* at once the direction, and the side whether N. or S., to which it tends.

In case of hesitation, it will suffice to remark that the white point of the needle is near to that point towards which one is going, whether E. or W.; read this letter (E. for example), then the degree is indicated by the white end (as 20° Fig. 4). Then still noticing this letter, and continuing *in the same direction* pass over 90°; you then arrive at one extremity of the line observed (S. by hypothesis). The *direction* will thus be announced as E. 20° S. corresponding to W. 20° N.

The frequent use of the pocket compass does not render less necessary exact observations of the underground workings by means of a "dial" or "theodolite." Upon well made "working plans" all changes of direction are laid down.† But it is with the pocket compass that the engineer should habituate himself to notice and approximately determine the variations of direction of different parts of the lode. This approximation becomes very satisfactory when two observers make observations in opposite directions in a strait part of a level, at distances of 5 to

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* The diameter is a little over two inches, the divisions are for every 2°, which are numbered at every 10°.

† A scale of 3 fathoms to one inch is convenient for working plans, and 15 fathoms to 1 inch for general plans.

10 fathoms. The footwall of the lode,—steep as it always is in the normal rich parts,—being well cleared, the two observers conveniently placed, and looking at each others lights, will arrive at the most complete numerical coincidence ; *good directions allow of good observations.*

THE END.

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* In Cornwall the terms *Huel* and *Wheal* are synonymous although I have followed Mr. Robert Hunt in generally adopting the former term. In quotations I have used the terms adopted by the respective writers.

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ERRATA.

P. 14, line 16, for *inclination* read *inclinations.*
P. 97, line 15 from bottom, for *enclose* read *intersect.*
Fig. 4, plate IV, for 42½° read 19°.

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